FINAL REPORT

Solar Cogeneration of Electricity and Hot Water at DoD Installations

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List of Acronyms

CP: Camp Parks
CPV: concentrating photovoltaic
DNI: direct normal irradiance
DoD: Department of Defense
ESTCP: Environmental Security Technology Certification Program
GHG: greenhouse gas
HPPA: heat and power purchase agreement
iBOS: integrated balance of systems
NBVC: Naval Base Ventura County
PH: Port Hueneme
PPA: power purchase agreement
PRFTA: Parks Reserve Force Training Area
PV: photovoltaic
PVT: photovoltaic and thermal
SHW: solar hot water

EXECUTIVE SUMMARY

Cogenra Solar, Inc. set out to demonstrate an innovative hybrid electric/thermal solar cogeneration system at Port Hueneme (Naval Base Ventura County) and the Parks Reserve Forces Training Area (PRFTA) (Dublin, CA), validate and document performance and cost advantages, and develop financing models and engineering tools to expedite transfer of the technology widely across DoD facilities.

Cogenra's approach combines proven PV and SHW technologies into a single integrated solar cogeneration system that extracts as much of the sun's incident power as possible as high-value electricity and delivers the rest as useful heat. Cogenra's SunDeck solar collectors are water-cooled concentrating PV (CPV) parabolic troughs that capture rather than dissipate what other PV approaches call "waste heat." The architecture comprises a series of ground or roof-mounted arrays that independently track the sun along one axis. Within each array, a series of flat mirrors concentrate sunlight (~8X) onto silicon-based PV-Thermal (PVT) panels that generate electricity. Conduits in the receiver panel carry a water-glycol mixture in a closed loop that cools the PV cells, enhancing their performance, and captures the excess solar energy as heat. A

compact SHW heat exchange/storage system transfers the heat to preheat the domestic water supply before it enters the site's pre-existing hot water heater.

The demonstration project included the installation of Cogenra systems at five separate buildings; three at Port Hueneme and two at PRFTA. The electricity and thermal energy delivered by these systems was measured for one year, and the systems continue to operate. The project set out to demonstrate that compared to standard PV and SHW arrays of the same size, Cogenra's system:

1) Generates at least 4.75X as much renewable energy (electricity + heat)
2) Delivers 2X the economic value
3) Reduces GHG emissions by 2.6X vs. PV and by 1.3X vs. SHW
4) Pays back the initial investment in energy cost savings in less time
5) Can accelerate compliance with DoD energy and environmental goals ~2X
6) Requires minimal operation and maintenance, comparable to PV and SHW

The SunDeck demonstration systems performed well and delivered over 4X as much renewable energy as a reference PV array, 1.7X the economic value as a reference PV array, and 1.4X the value of a reference SHW array. These gains were somewhat less that the stated performance goals, primarily due to inconsistent hot water usage in some of the buildings, especially the barracks. Low or inconsistent hot water demand limits the utilization of the cogeneration system overall, but especially the amount and value of the heat delivered. Similarly, the Cogenra systems demonstrated greater GHG emissions reduction than PV or SHW, though slightly less than the target due to system utilization.

Lifecycle cost analysis demonstrated that the Cogenra systems offer a payback period of 5.1 years, ½ to ⅔ the payback time of PV or SHW. The results of the project demonstrated the increased value of cogeneration, enabling accelerated and cost-effective compliance with the DoD's energy and environmental goals. Operation and maintenance requirements have been similar to PV or SHW and the systems continue to operate successfully.

Lack of demand impacted the performance of the array during the demonstration since when there is no off-take for the thermal energy generated by the solar array; the solar thermal storage tank reaches its upper temperature limit and triggers the solar array to de-track to mitigate over-heating. During de-tracking the array produces neither electricity nor solar hot water and this will in-turn impact the economics of the project.

1 INTRODUCTION

Over the next two decades The DoD intends to dramatically increase its usage of renewable energy. This is part of a concerted effort to reduce life-cycle costs and green house gas emissions.

This project has demonstrated the ability of Cogenra Solar's SunDeck system to generate significantly more renewable energy, energy value, and greenhouse gas (GHG) reductions compared with widely available solar photovoltaic (PV) and solar hot water (SHW) technologies, while also reducing cost.

1.1 BACKGROUND

Cogenra's approach combines proven PV and SHW technologies into a single integrated solar cogeneration system that extracts as much of the sun's incident power as possible as high-value electricity and delivers the rest as useful heat. By sharing equipment and installation costs across the PV and SHW roles, Cogenra's approach can generate substantially more renewable energy at relatively low incremental cost over PV or SHW alone, yielding far more attractive economics.

Conventional photovoltaic systems (PV) convert less than 20% of the sun's incident energy into electricity and struggle to dissipate the remaining 80+% as heat. Low efficiency requires large systems to generate a significant amount of renewable energy and contributes to PV's further struggle to achieve cost parity with the grid. These issues severely limit the number of cost-effective deployment opportunities at DoD facilities. Conventional solar hot water (SHW) systems are mandated by EISA §523 (strengthened by recent DoD directives[i]) but suffer from even longer payback times than PV. [ii]

Compared with a state-of-the-art PV array of the same size, Cogenra's system

- Generates ~5X as much renewable energy (the same amount of electricity + 4X that amount as useful heat),
- Delivers ~2X as much energy value (since heat is usually worth less than electricity),
- Eliminates at least 2.6X more greenhouse gas emissions (weighted by GHG intensity of the offset sources), and
- Pays back the initial investment through accrued energy cost savings in 25% less time.

Similar economic advantages apply in comparison to a state-of-the-art solar hot water system.

1.2 OBJECTIVE OF THE DEMONSTRATION

Cogenra Solar, Inc. set out to demonstrate an innovative hybrid electric/thermal solar cogeneration system at Port Hueneme (Naval Base Ventura County) and the Parks Reserve Forces Training Area (PRFTA) (Dublin, CA), validate and document performance and cost advantages, and develop financing models and engineering tools to expedite transfer of the technology widely across DoD facilities.

In order to measure the baseline hot water usage profile of the building comprising the demonstration project, Cogenra and subcontractors installed hot water meters that measure flow and temperature at each building. Utilizing these water meters, Cogenra tracked the hot water

consumption profile of all buildings comprising the project for a full year. The objective of this baseline metering was to aid in the calculation of cost savings and GHG reductions brought about by the cogeneration system.

The demonstration project included the installation of Cogenra systems at five separate buildings; three at Port Hueneme and two at PRFTA. The electricity and thermal energy delivered by these systems was measured for one year, and the systems continue to operate. The renewable energy delivered, traditional energy usage offset, and the corresponding economic benefits were the data used to demonstrate the key performance and cost advantages of the cogeneration system.

As detailed in Section 3: Performance Objectives, the project set out to demonstrate that compared to standard PV and SHW arrays of the same size, Cogenra's system:

- Generates at least 4.75X as much renewable energy (electricity + heat)
- Delivers 2X the economic value
- Reduces GHG emissions by 2.6X vs. PV and by 1.3X vs. SHW
- Pays back the initial investment in energy cost savings in less time
- Can accelerate compliance with DoD energy and environmental goals ~2X
- Requires minimal operation and maintenance, comparable to PV and SHW

A further goal of the demonstration project was to expedite technology transfer to, and wide adoption within the DoD. The project objectives therefore included guidance documentation and other deliverables to ease and expedite solar cogeneration technology transfer:

- Final Cost and Performance Report – Reports prepared for ESTCP to document performance and cost for solar cogeneration systems demonstrated at military installations.
- Decision Tools – Developed to enable energy managers, energy consultants and resource efficiency managers to easily assess the suitability and lifecycle cost return of solar cogeneration technology at DoD installations.
- Design Tools and Engineering Templates – Developed for the engineers who will design a specific system after the decision has been made to build it. These tools can significantly reduce engineering time and cost, and enable engineers without prior experience with solar cogeneration to design and implement new projects. These tools will also enable DoD installations to utilize a wider array of contractors to design and install solar cogeneration systems.
- HPPA Guidance – Cogenra worked with financial partners to develop the industry-leading Heat and Power Purchase Agreement (HPPA). These HPPAs enable customers to purchase energy at predictable prices without any capital outlay or debt, no performance risk or maintenance cost while gaining all the benefits of renewable energy, such as reduced emissions and energy savings. Cogenra has developed economic tools that take

into account the solar resource available, installation costs and energy demand to provide guidance for the HPPA energy prices that can be achieved by Cogenra systems and financial partners. This is performed on a case-by-case basis.

The demonstration sites were selected with high visibility as a priority to facilitate technology transfer to follow-on sites:

- NAVFAC Engineering Services Center, which is responsible for evaluation of energy technologies for the Navy and Marine Corps, is headquartered at Port Hueneme.
- PRFTA is a pilot net-zero energy installation for the Army. It serves as a model for other installations across the country, so the project provides high visibility to Army energy managers.

Additional benefits of Cogenra's solar cogeneration system are the engineering and design jobs at Cogenra's headquarters in California and manufacturing jobs at suppliers throughout the US. With the demonstration complete, the DoD now has five operational solar cogeneration systems that will continue to provide renewable electricity and hot water for more than 20 years.

1.3 REGULATORY DRIVERS

The DoD aims to "produce or procure 18.3% of all energy consumed within its facilities during FY 2020 from renewable energy sources (thermal as well as electrical)"[iii] and the 2010 National Defense Authorization Act §2852 mandates 25% by FY2025. DoD has further committed to reduce GHG emissions from Scope 1 and 2 sources (controlled by DoD or resulting from energy purchased by DoD) by 34% by FY2020 relative to FY2008. EISA §523 also requires that "If lifecycle cost-effective, as compared to other reasonably available technologies, not less than 30% of the hot water demand for each new Federal building or Federal building undergoing a major renovation be met through the installation and use of solar hot water heaters." EO 13423 §2(b) emphasizes new renewable sources and implementation of renewable energy projects on federal land.

Achieving these ambitious renewable energy and GHG goals on schedule will require maximum utilization of solar power generation opportunities. Solar cogeneration will enable DoD to achieve its goals faster — (i) by creating many more deployment opportunities that are cost-effective, and (ii) by delivering greater energy benefits, energy security benefits, economic benefits and GHG benefits for each new project commissioned.

Cogenra's system can also help new and existing buildings achieve LEED certification. Solar cogeneration can help earn LEED points in three areas: Optimizing Energy Efficiency Performance, On-Site Renewable Energy, and Heat Island Reduction. For existing buildings up to 15, 4 and 1 points can be earned in each category respectively.

2 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

Cogenra's solar collectors are water-cooled concentrating PV (CPV) parabolic troughs that capture rather than dissipate what other PV approaches call "waste heat." The architecture comprises a series of ground (Figure 1) or roof-mounted (Figure 2) arrays that independently track the sun along one axis. Within each array, a series of flat mirrors concentrate sunlight (~8X) onto silicon-based PV-Thermal (PVT) panels that generate electricity. Conduits extruded directly through the panel substrate carry a water-glycol mixture in a closed loop that cools the PV cells, enhancing their performance, and captures the excess solar energy as heat. A compact SHW heat exchange/storage system transfers the heat to preheat the domestic water supply before it enters the site's pre-existing hot water heater.

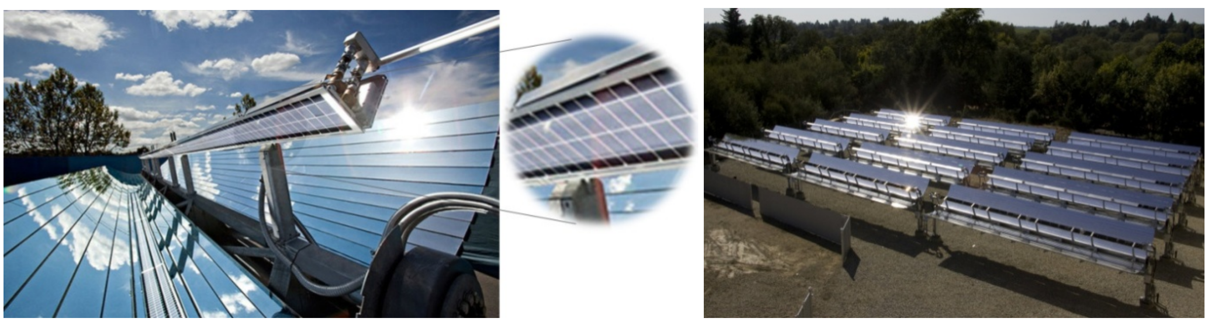

Figure 1: (left) Cogenra's original SunBase solar array configured from ground-mounted applications. (right) Commercial system (272 kWp) operating at the Sonoma Wine Company in Graton, CA.

Figure 2: Cogenra's SunDeck system configured for roof-mounted applications. Shown above is a system at General Hydroponics in Santa Rosa, CA.

Each roof-mounted SunDeck module comprises one half-parabola that focuses onto a single PVT panel mounted above the mirrors along the focus line. The module axis can be oriented in any orientation, and the module pivots around that axis to track the sun. This configuration enables a much lower profile, lower wind loading, and lighter weight (5 psf total) than the ground-mounted

SunBase, and is suitable for nearly all types of roofs with a pitch of up to 20°. A SunDeck module can be mounted on roofs or on the ground and the axis can be oriented in any direction, as appropriate to the particular installation.

Though the concept is simple, Cogenra has had to pioneer several key technical and business innovations:

- **PV-Thermal (PVT) Panels —** Cogenra developed a proprietary method to laminate PV cells directly and reliably to an inexpensive extruded aluminum back-plate with internally integrated liquid coolant conduits, combining excellent thermal coupling reliably with strong electrical insulation.
- **Collector —** Cogenra designed a novel collector configuration that inexpensively replicates the uniform concentration of solar flux reflected by a parabolic mirror, but with several key advantages:
  - Fixed flat mirrors, which are far less expensive to produce and align than curved mirrors,
  - High strength, since the rugged mirrors are reinforced by gluing them onto a metal carrier structure,
  - No shading of the cells, achieved in a design that does not sacrifice the collector's structural integrity.
- **Hydronics —** Cogenra has integrated the hydronics components (pumps, valves, sensors, etc.) into a standardized skid mounted configuration that dramatically simplifies the engineering requirements for each new project and enables lower-cost assembly and testing offsite. (In this project we have extended this approach to further modularize and integrate the balance of system components.)
- **Supply chain** — Cogenra designed the system so that all components can be readily sourced from well-established vendors without incurring supply chain constraints and without raising reliability issues:
  - *PV Cells* — standard silicon cells with one minor vendor customization: a denser grid of metal contacts is deposited in the final cell fabrication step to carry the higher currents generated from concentrated light.
  - *PVT Panels* — produced in production lines similar to standard silicon module production with standard certified materials.
  - *Mirrors* — sourced from multiple US vendors employing standard flat glass manufacturing processes.
  - *Collector Frame* — readily sourced from any metal fabrication shop locally near the installation site.
  - *Merge-at-Site Logistics* — The mirrors, frames, PVT panels, and hydronics units (which are all manufactured or assembled at different locations in the US) all stack compactly and are transported independently to the site for final assembly.

2.2 TECHNOLOGY DEVELOPMENT

This ESTCP project included some technology development work prior and in addition to the actual field demonstration project. Specifically, this included the Cogenra iBOS and monitoring software.

The Cogenra SunDeck iBOS, for “integrated Balance Of Systems”, was developed in order to combine balance of systems and controls for the cogeneration system in a single package. The iBOS includes:

- PV DC-AC inverter
- hydronics components including the pump, fluid temperature sensors, pressure relief valve, and the other necessary valves and connections
- electrical power and field connections
- SunDeck system control board and communication connection
- NEMA 4X enclosure

Integrating all of these components and functions into a single unit streamlines manufacturing and simplifies system installation, both of which reduce the installed cost of the system. The iBOS also enables the monitoring system to communicate with all sensors and actuators in the array.

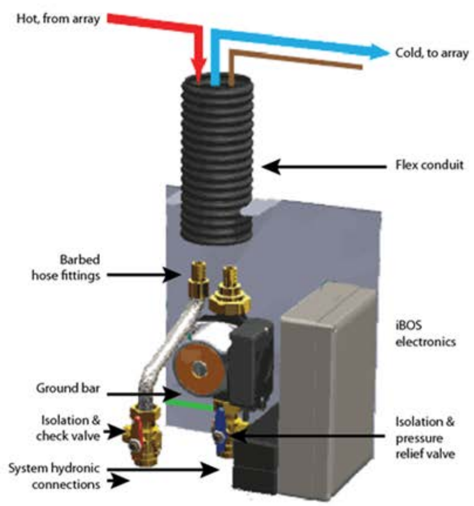

Figure 3: Cogenra iBOS, showing internal hydronics components (left) and location on the system with the PV inverter (right)

Cogenra developed software that allows a system owner or operator to buy an option to monitor the performance of the SunDeck system through a web interface. To access the data for the SunDeck systems that they own or operate, the user must enter their login credentials on

Cogenra's monitoring site. An example screen from the monitoring site is shown in Figure 4. The user can monitor the electrical and thermal energy delivered by the system on a monthly, daily or hourly basis. The monitoring site also allows for downloading the data in XLS format.

Cogenra has also developed additional monitoring software tools that access more detailed data from all sensors on the SunDeck system, although these additional monitoring tools are beyond the scope of what is available to external users. See Sections 5.5 and 5.6 for more information.

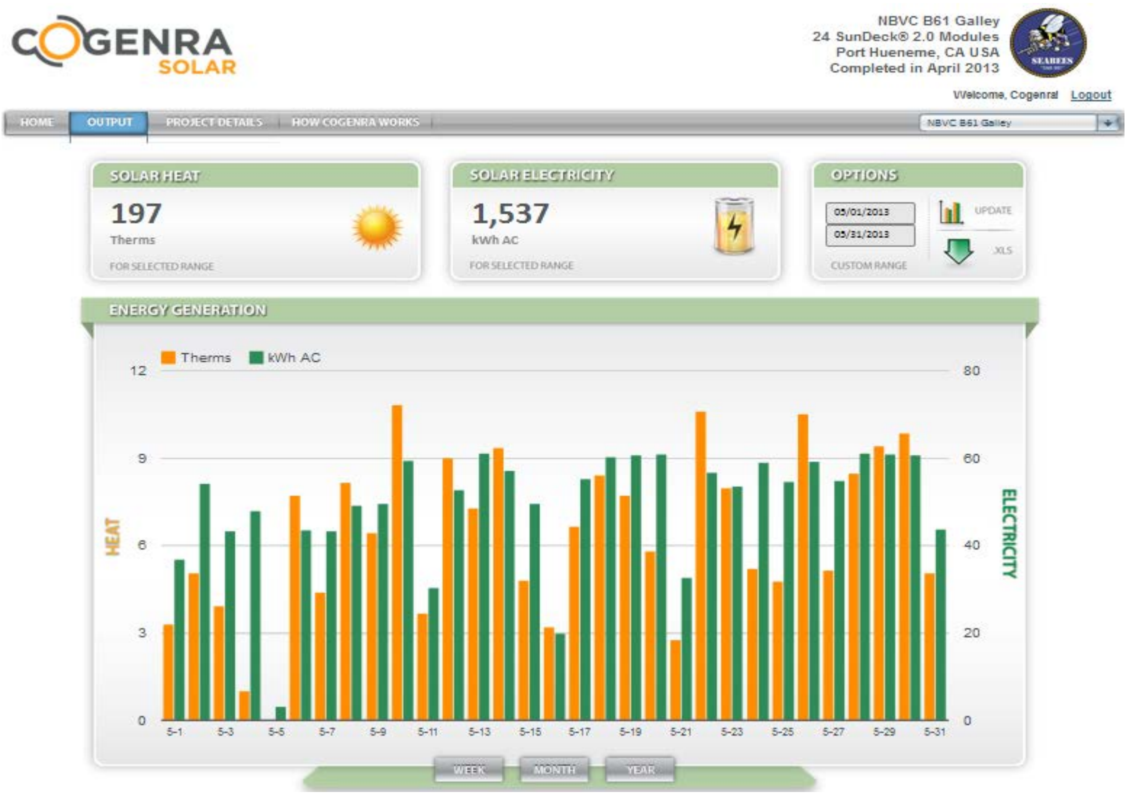

Figure 4: Screenshot showing Cogenra's monitoring page as viewed by the customer.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Here we describe some of the advantages and limitations of Cogenra's solar cogeneration technology as compared to relevant alternative technologies, especially flat-panel PV and SHW arrays. To provide the most accurate and broadly applicable information, we present a summary that draws from the results of many Cogenra installations, including the demonstration projects at Port Hueneme and PRFTA as well as a variety of civilian installations.

The advantages of Cogenra's technology include:

- Delivers 4-5X the total renewable energy (electricity and heat) per unit of installed module area compared with conventional PV

  - Maximizes renewable energy production intensity to best utilize limited premium space such as rooftops
  - Reduces lifecycle costs by delivering more energy per unit of solar infrastructure installed
  - Enables the DoD to achieve renewable energy targets on schedule by adding far more renewable energy capacity per project commissioned and by increasing the number of cost-effecting deployment opportunities
- Eliminates 2.6X more GHG emissions per unit area compared with conventional PV
  - Achieves greater GHG reductions because the cogeneration system displaces more energy (the impact is not 4-5X because the GHG intensity factors for offsetting electricity generation and offsetting natural gas consumption differ)
  - Enables the DoD to achieve GHG reduction targets on schedule by eliminating more emissions per new project
- Enables installations to economically satisfy the recently strengthened 30% solar hot water mandate,[i] which otherwise will be challenging to meet cost effectively,[ii] **Error! Bookmark not defined.**as a nearly free added benefit to PV projects (Cogenra solves the cost problems of SHW by sharing components with PV and leveraging tracking)
- Achieves significantly faster payback time than a PV system of comparable area on the same site
  - Faster because it delivers far more energy at small incremental installed cost: for a wide range of specific *commercial* scenarios that Cogenra has analyzed rigorously, the typical spread in payback time is 4–6 years for Cogenra's system vs. 8–12 years for PV alone and 12-20 years for SHW alone (the precise advantage depends on site-specific details such as relative electric vs. gas utility rates, climate, insolation, financing structure and incentives); *military* sites do not benefit from tax breaks and impose stricter design requirements, which raises all these numbers, but we believe solar cogenerations' *relative* advantage does hold.
- Includes advanced controls and energy management logic to optimize energy generation to consumption patterns.
- Maintenance for Cogenra's SunDeck system is fairly minimal and thus requires little training. In general, operation and maintenance requirements are similar to standard PV and SHW systems. The systems have built in diagnostics that will alert the system owner if maintenance is needed. The owner can also monitor performance online. The following preventative maintenance items are recommended, but they are not necessary if power output continues to meet expected design parameters:
  - Annual visual inspection of the system. (No special training is required.)
  - Mirror washing during the dry months may be indicated. The rate at which dirt accumulates and the degree to which rain removes the dirt depends on the site.

Cleaning the mirrors requires only a garden hose, a squeegee mounted on a handle, and a lint-free cloth. No special training is required to clean the mirrors and the instructions are easy to follow. The systems at Port Hueneme and PRFTA were cleaned one or two times per year on average as needed during this demonstration period.

  - Comprehensive inspection of the system every five years, including testing of the glycol solution. This should be performed by a trained technician but the system owner can perform all tests.

The limitations of Cogenra's technology include:

- All distributed solar hot water systems require adequate and consistent hot water demand in order to perform at their full potential (This limitation was observed during certain periods for the systems installed at the barracks buildings, as discussed in Section 3 and Section 6). For buildings with small or inconsistent hot water usage, return on investment from a solar cogeneration or SHW project will generally be less attractive than sites with greater hot water demand. This can be mitigated with any of the following solutions:
  1. Combining the water heating loops of multiple buildings can often enable cost-effective solar water heating for a group of buildings.
  2. In cases where hot water demand is inadequate, Cogenra's system architecture can instead be configured to cheaply dissipate some or all of the captured heat. Costs in this case are competitive with standard PV, and the system can always be retrofitted to deliver the captured heat if energy demands change in the future.
  3. Increasing the size of the hot water storage tank to accommodate the excess heat during times of high production and low demand. However, this solution has limitations if periods of low heat demand are extensive in duration or unpredictable.
- Concentrating solar technologies are most cost-effective in locations with high direct normal irradiance (DNI). Cogenra recommends DNI of at least 1600 kWh/m^2/year, although places with lower direct irradiance may still be attractive depending on energy costs and renewable energy goals. Note that Cogenra's tracking low-concentration cogeneration system typically captures far more energy than fixed PV or SHW systems, and advantageously shares the cost of tracking with both PV and thermal components.

3 PERFORMANCE OBJECTIVES

Table 1: Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
1) Increase renewable *energy* delivered per unit area	kW-hr / yr-m^2	Energy delivered; meteorological readings; comprehensive tracking of all internal parameters (to optimize performance)	475% of reference PV system 935 kW-hr / yr-m^2 (module area)	408% vs. PV 825 kW-hr/yr-m2
2) Increase renewable energy *economic value* delivered per unit area	\$ / yr-m^2	Energy delivered by type (electricity, heat); utility rates for offset energy	200% of reference PV system 200% of reference SHW system \$45 / yr-m^2 in energy savings	171% vs. PV 140% vs. SHW \$44.82/yr-m2
3) Reduce GHG emissions with a larger benefit per unit area	MT CO_2e / yr-m^2	GHG lifecycle analysis; energy delivered by type; baseline GHG emissions for offset energy sources (grid/natural gas)	260% of reference PV system 130% of reference SHW system 0.3 MT CO_2e / yr-m^2 offset GHG	230% vs. PV 115% vs. SHW 0.28 MT-CO_2e/yr-m^2
4) Reduce payback time	years	Lifecycle cost analysis; energy delivered	70% of reference PV system 60% of reference SHW system <10 years (hypothetical HPPA)	56% of the reference PV system 65% of the reference SHW system 5.1 year payback solar cogeneration (see table in Section 6.4)
Qualitative Performance Objectives				
5) Accelerate compliance with DoD energy / environmental goals	per system basis	Validation of performance objectives listed above; assessment of legal requirements and directives	Approximately twice the benefit / speed toward reaching goals	Results demonstrated the increased value of cogeneration vs. PV or SHW alone
6) Low maintenance requirements	SOPs	Operating and maintenance history; tests of automated monitoring systems	Comparable to PV and SHW	Similar to standard SHW and PV

The metrics that are expressed per unit area utilize the aperture area of the system. The aperture area of the Cogenra SunDeck is the projected area of the mirror bed that receives and re-directs sunlight to the receiver. Similarly, for PV and SHW modules, aperture area is equivalent to active module area.

1) Increase renewable energy delivered per unit area.

This objective is straightforward: the Cogenra system should deliver 4.75x more energy per unit area than a standard PV array in the same location. Conventional photovoltaic systems (PV) convert less than 20% of the sun's incident energy into electricity and struggle to dissipate the remaining 80+% as heat. Cogenra's solar cogeneration system captures this thermal energy as useful heat, and thus can deliver 5x the energy or more per unit module area. The success criterion is set at 4.75x to provide a reasonable margin.

The relevant metric is energy converted or delivered per unit gross module area, per year. This objective refers to total energy, both electrical and thermal. This demonstrates one of the core advantages of a cogeneration system.

The implementation of the Cogenra array and systems on top of the buildings in PRFTA and Port Hueneme was performed mainly adhering to the roof structural design. The main impact of this roof structural design was on the module orientation with respect to the azimuth angle. The demonstration included some modules oriented north-south (180 degree azimuth) and others in the east-west direction. The modules oriented in the north-south direction generated nominally 15% more overall annual energy than those oriented east-west, however, those oriented east-west had higher production during the winter months. Higher production during the winter months is well optimized for building heating loads since heat is more required in winter than in summer.

The output of the reference PV system was simulated using industry-standard PV performance modeling methods, based on the actual measured solar irradiance and ambient conditions measured by Cogenra's weather stations at each site. PV performance results were validated against industry-standard modeling tools including PVsyst and NREL PVWatts. Additionally, one reference fixed-tilt PV panel was installed at each base alongside the Cogenra system, and the power output was measured continuously. This allowed for excellent validation of our comparison to standard PV.

Detailed results are presented and discussed in Section 6: Performance Assessment, and summarized in Table 1. Normalized per year and per unit area, the Cogenra systems delivered 408% the renewable energy of the reference PV array. The total energy was 825 kWh/yr/m^2. The corresponding success criteria laid out in the demonstration plan were 475% and 935 kWh/yr/m^2. The energy delivered by the systems was limited by inconsistent hot water usage at some of the buildings, preventing the full utilization of the cogeneration system. This is the main reason identified for observed performance that is slightly short of the target set in Performance Objective #1. Adequate and regular heat usage is essential for fully realizing the benefits of any

system that includes solar water heating. In general, we observed that hot water usage was particularly inconsistent at the barracks, which were not always occupied. Hot water usage at the kitchens was more consistent.

Supporting analysis regarding the issue of hot water usage is given in Section 6. Additionally, detailed results on hot water usage are provided in the "baseline profile" sections.

2) Increase renewable energy economic value per unit area.

Demonstrating this objective involves convolving the performance data from the first objective with the utility rates paid by the sites. The metric used is economic value per unit of installed module area per year, $/yr/m^2. This metric quantifies the energy cost savings that benefit the user.

Detailed results are presented and discussed in Section 6: Performance Assessment, and summarized in Table 1. Normalized per year and per unit area, the results show that the Cogenra systems delivered $44.82/yr/m^2 of savings. This was 171% the value of the reference PV array and 140% the value of the reference SHW array.

Although the Cogenra demonstration system provided much greater economic value than the reference PV or SHW arrays, the gain was less than the goal of 200% stated in Performance Objective #2. The primary reason for the difference was the inconsistent hot water usage at some of the buildings, especially the barracks. Inconsistent hot water demand limits the utilization of the cogeneration system overall, but especially the amount and value of the heat delivered. This is why the value added with respect to the reference system was less in the case of water heating than electricity generation, in this demonstration project.

3) Reduce GHG emissions with a larger benefit per unit area.

Demonstrating this objective involves convolving the performance data from the first objective with the GHG intensity factors of the offset energy sources, and also factoring in the "upstream emissions" associated with manufacturing and installing the system. Life Cycle Associates (LCA), an independent consulting firm specializing in life-cycle greenhouse gas analysis has already determined the appropriate baseline emissions factors and completed an upstream analysis of Cogenra's system. Cogenra's typical 2.6X GHG advantage relative to PV reflects the fact that solar cogeneration produces more renewable energy from a system of the same size, and thus offsets more fossil-fuel consumption. The advantage relative to SHW reflects the greater GHG intensity off offset electricity compared with heat; the factor of 1.3X is a typical lower bound that does not account for the higher energy production of Cogenra's tracked system relative to conventional SHW.

Detailed analysis and results regarding GHG emissions are presented in Section 6: Performance Assessment, and summarized in Table 9. Normalized per year and per unit area, the results show

that the Cogenra systems resulted in 0.284 MT-CO2e/yr/m^2, just slightly less than the goal of 0.3 MT-CO2e/yr/m^2 stated in Performance Objective #3. This was 230% the GHG offset by the reference PV array and 115% the GHG offset by the reference SHW array.

4) Reduce payback time.

Detailed cost and payback analysis was performed for the Cogenra system and in comparison with reference PV and SHW systems. The results are presented in Table 8. The results show that solar cogeneration payback is 56% of reference PV system, significantly out-performing the success criteria. The payback comparison to reference SHW also shows that the SunDeck system's payback is 65% of reference SHW. The SunDeck system's thermal payback is slightly above the reference SHW success criteria of 60%; this is mainly attributable to the usage limitations seen when the barracks were unoccupied. Thus the system was not 100% utilized to full potential.

These analyses are based on sizing the reference PV and SHW to match the respective energy production of the solar cogeneration array and for the SHW system 100% of its output was assumed to be utilized.

5) Accelerate compliance with DoD energy/environmental goals.

As discussed in Section 1.3, the DoD aims to "produce or procure 18.3% of all energy consumed within its facilities during FY 2020 from renewable energy sources (thermal as well as electrical)"[iv] and the 2010 National Defense Authorization Act §2852 mandates 25% by FY2025. DoD has further committed to reduce GHG emissions from Scope 1 and 2 sources (controlled by DoD or resulting from energy purchased by DoD) by 34% by FY2020 relative to FY2008.[iii] EISA §523 also requires[i] that "If lifecycle cost-effective, as compared to other reasonably available technologies, not less than 30% of the hot water demand for each new Federal building or Federal building undergoing a major renovation be met through the installation and use of solar hot water heaters." EO 13423 §2(b) emphasizes new renewable sources and implementation of renewable energy projects on federal land.

By delivering more renewable energy and offsetting more GHG emissions from available roof space, available land, and available project funds, Cogenra's system enables The DoD to reach its goals more rapidly than relying on conventional solar technologies. The DoD's energy and environmental goals are diverse, and the Cogenra system can help to accelerate compliance in several ways. Overall, the results from the demonstration project as well as other Cogenra installations support an approximately two-fold acceleration towards cost-effective compliance with these goals. Additional discussion is given in Section 6.

6) Low maintenance requirements.

Operation and maintenance (O&M) requirements are an important component of the lifetime cost and reliability of any project. Cogenra's solar cogeneration technology combines and adapts

technologies found in PV systems (PV modules, electrical wiring, inverters, trackers) and SHW systems (hydronics, piping, pumps, heat exchange with building hot water loop) and thus has similar maintenance requirements. Cogenra's monitoring software (developed as part of this demonstration project) monitors all sensors on the system as well as several additional performance metrics. This monitoring system allows for automatically detecting any specific maintenance needs and alerting the owner or operator. More generally, the performance monitoring helps to determine whether any "regular" or discretionary service (such as mirror washing or system inspection) is needed.

This qualitative performance objective was to demonstrate that the Cogenra system has low maintenance requirements that are similar to typical PV and SHW systems. Operation and maintenance history from these demonstration sites as well as Cogenra's many commercial installations support this description. Specific information on the maintenance carried out at the PRFTA and Port Hueneme sites is given in Section 6.

4 FACILITY/SITE DESCRIPTION

The demonstration project included both a Navy and an Army facility, in order to expedite technology adoption after the project ends. PRFTA, in Dublin, CA has a total of two installations; one each of 28 and 32 modules. Port Hueneme, near Oxnard, CA has a total of three installations; two of 24 modules and one of 36 modules. Each module has 3.5m2 projected area.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Port Hueneme, a facility within Naval Base Ventura County (NBVC) on the southern coast of California, hosted the primary demonstration. This project site includes three discrete SunDeck arrays installed on the roofs of these buildings:

- PH61 (Dining Facility / Galley) — 24 modules oriented N-S
- PH1481 (Bachelor Enlisted Quarters) — 24 modules oriented E-W
- PH1517 (Quad Bachelor Quarters: four buildings with a central heating plant) — 36 modules oriented N-S

The total system nameplate energy production is 200 kW (36 kW-e + 164kW-th) including the three arrays.

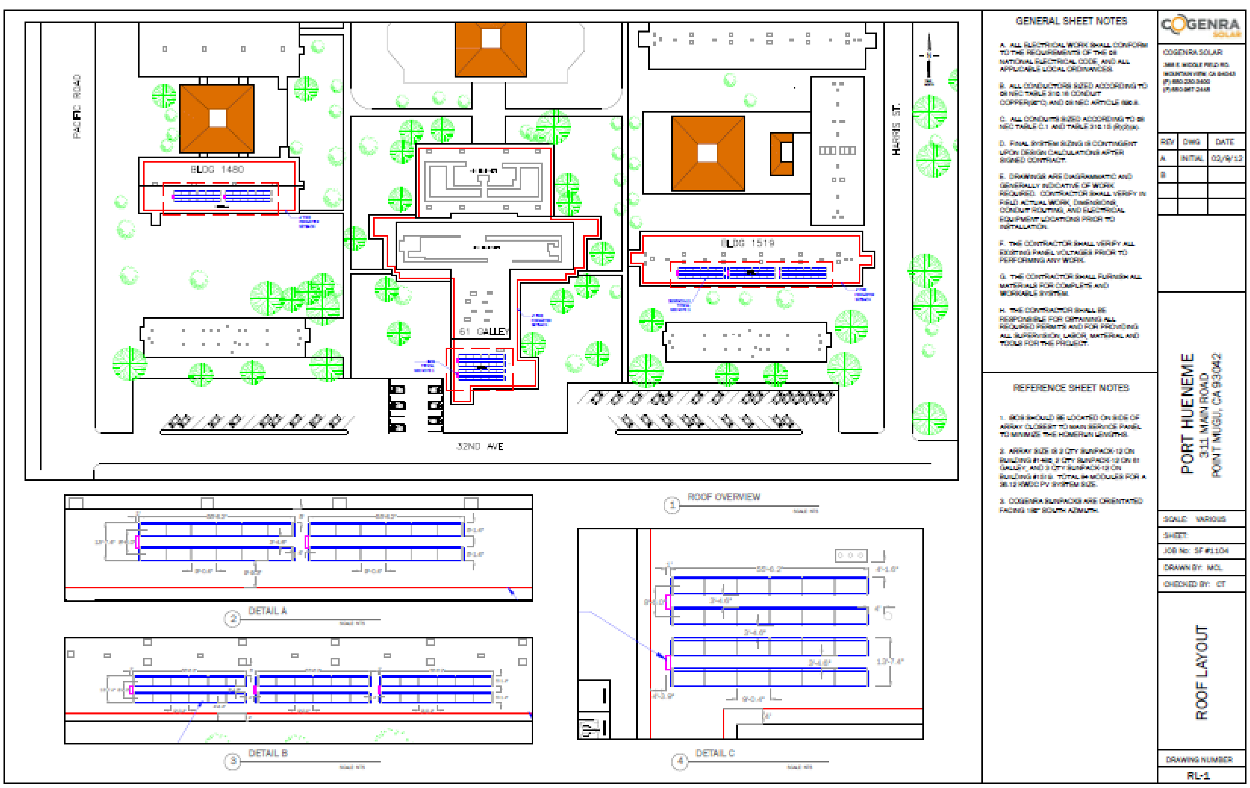

Figure 5: Port Hueneme Plan View

Parks Reserve Forces Training Area (PRFTA), an Army Reserve Component mobilization and training facility located in Dublin, CA, hosted the second demonstration. Since the Army selected PRFTA as one of six pilot net zero energy installations, it has a particularly strong need to identify renewable energy technologies, such as solar cogeneration, that maximize production of energy from the sun and that offset multiple types of energy use. PRFTA has also provided an excellent test-bed for Cogenra to optimize and demonstrate the ability to tune the balance between electricity and thermal production (in order to maximize either total energy production or energy value created) for a DoD customer that is actively striving to meet stringent energy targets.

The PRFTA site includes two discrete SunDeck arrays installed on the roofs of these buildings:

- PRFTA 332 (Dining facility) – 28 modules oriented E-W
- PRFTA 394 (Bachelor Enlisted Quarters) – 32 modules oriented N-S

This project site includes two discrete SunDeck arrays for (i) a Dining Facility and (ii) a pair of Bachelor Enlisted Quarters (Buildings 393 and 394) and Laundry Facility (Building 398). The two BEQs and laundry are served by a single SunDeck array, creating a simple district-heating configuration that can serve as a model for wider district implementations in the future that involve multiple buildings. The total system nameplate energy production is 140 kW (25 kW-e + 115 kW-th) including both arrays.

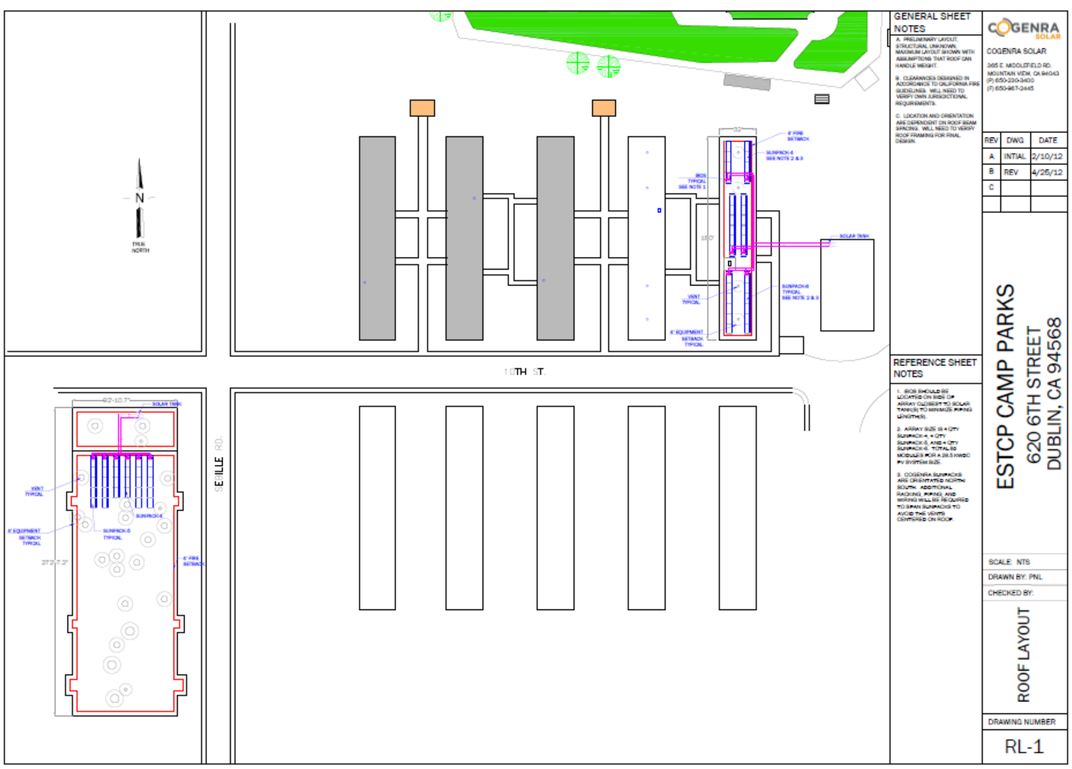

Figure 6: PRFTA Plan View

Figure 7: Photos from the installations at Port Hueneme and PRFTA. In addition to the SunDeck systems, a hot water tank, weather monitoring station and traditional PV reference panel are also shown.

4.2 FACILITY/SITE CONDITIONS

Specific site conditions are important for any renewable energy project, and especially for rooftop installations. Comments and observations from Cogenra's field operations team are summarized below for the demonstration installations.

Port Hueneme, overall

- Early morning fog and cloud cover at Port Hueneme NBVC

Port Hueneme, Building 1517 (Barracks)

- Difficult roof access at this building

Port Hueneme, Building 1481 (Barracks)

- Difficult roof access at this building

PRFTA, Building 332 (Kitchen)

- Canadian geese visit this roof and occasionally leave droppings on the systems

PRFTA, Building 394 (Barracks)

- Ladder access required
- Safety line tie-off required due to roof edge proximity to the system (no parapet)
- Near a lot of dry open area that may contribute to mirror soiling
- Canadian geese visit this roof and occasionally leave droppings on the systems

5 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The test plan and design was detailed in Cogenra's Demonstration Plan, and followed throughout the course of the two-year project. The demonstration project was designed to test how much Cogenra's solar cogeneration system outperforms traditional PV and SHW systems. The performance of Cogenra's system was measured and compared to calculated performance numbers for photovoltaic and solar hot water systems.

The key performance parameters were: how much renewable energy is produced per square foot of solar system, the dollar value of the renewable energy produced per square foot of solar system, the reduction in green house gas emissions per square foot of solar system and the payback period of the solar system.

These values were measured while at the same time controlling for external factors such as hot water demand and weather. This allows us to provide an "apples to apples" comparison of the different renewable energy systems.

In scientific terms this is an experiment with a changing independent variable, measured dependent variables and controlled variables. The independent variable is the presence of Cogenra's system vs. the presence of traditional PV and SHW systems. The dependent variables are the measured values that change depending on the technology used. Specifically: the renewable energy production per unit area (kW-hr / yr-m2), economic value of renewable energy per unit area ($ / yr-m2), reduced GHG emissions per unit area (MT CO2e/yr-m2), and a reduced payback time. The controlled variables are the hot water demand and the weather conditions.

The hypotheses was that the Cogenra system would demonstrate improved performance over the reference system as described in the success criteria of Table 1, Performance Objectives.

The key technical tasks, tests, and technical and economic assessment methods were as follows:

Task 1: Install energy consumption metering
Cogenra installed meters to measure the flow rate and temperature of hot water exiting the water heaters of all buildings comprising the demonstration project at Port Hueneme and PRFTA.

Task 2: Assess site's baseline energy consumption
Utilizing the water meters installed in Task 1, Cogenra tracked the hot water consumption profile of the buildings comprising the demonstration project for 1.5 years and has correlated the results with season, weather, occupancy, time of day, day of week and other factors via regression analysis. The baseline profiling partly overlapped the operational period of the project, which is

expedient since generation and consumption should be largely decoupled, but we have accounted for any systematic differences in the consumed hot water temperature before/after installation.

Task 3: Design demonstration project –*and*- Task 4: Build demonstration project

Cogenra worked with the general contractor for each project site in order to carry out the design and construction of the demonstration project.

Contractor tasks included:

- Complete all preliminary, development and engineering designs and obtain site approval and design approvals from the Facilities, Engineering and Acquisition Division (FEAD) at Pt. Hueneme and the Directorate of Public Works (DPW) at PRFTA.
- Prepare the Quality Control Plan, Environmental Plan, Safety Plan, and Fault Protection Plan and obtain all necessary permits and approvals related to these plans from FEAD/DPW.
- Manage all activities relating to site preparation, delivery of major equipment, construction, installation, quality control assurance, clean up, and initial turn on and validation of the demonstration systems.
- Obtain final inspections, approvals, and oversee commissioning of the projects.

Cogenra provided engineering and logistical support and procured the components of the SunDeck modules from established, qualified vendors.

The implementation of the Cogenra array and systems on top of the buildings in PRFTA and Port Hueneme was performed mainly adhering to the roof structural design. The main impact of this roof structural design was on the module orientation with respect to the azimuth angle. The demonstration included some modules oriented north-south (180 degree azimuth) and others in the east-west direction. The modules oriented in the north-south direction generated nominally 15% more overall annual energy than those oriented east-west, however, those oriented east-west had higher production during the winter months. Higher production during the winter months is well optimized for building heating loads since heat is more required in winter than in summer.

Engineers from Cogenra toured and inspected the facilities at Pt. Hueneme and PRFTA and held extensive discussions in advance with the base energy manager and resource efficiency managers. Based on the visits and preliminary engineering analysis, Cogenra prepared a detailed budget for Tasks 3-4 for the project at Pt. Hueneme and PRFTA.

Task 5: Operate project, monitor and optimize

Cogenra has so far operated the demonstration systems at Pt. Hueneme and PRFTA for one full year since commissioning, monitored their performance across seasons, and utilized the operating data in combination with energy usage data to optimize the amount and value of renewable energy delivered. As described in the demonstration plan, we have:

- Measured energy produced and energy delivered to each base (separately for heat and electricity) and other diagnostic parameters. The system controller automatically records the following parameters and securely transmits the data to Cogenra: direct normal irradiance and diffuse horizontal irradiance (recorded by a dedicated pyranometer); ambient temperature; glycol loop fluid temperature in and out, and flow rate; domestic water supply temperature into the preheat tank, out to the main storage tank, out to the building for consumption, and flow rate (customer side for each building); preheat water tank temperature; Imp, Vmp, Pmp DC, Pmp AC (for each of the inverters); and tracker angle (per array section). Addresses Performance Objective #1 and #5 (PO1&5).
- Compared these data with a sophisticated predictive model that Cogenra has developed. The model predicts the PV and thermal outputs of the system based on the system dimension, calculated sun angle, measured insolation, mirror reflectivity and PV response of a typical receiver (previously measured in the laboratory), various thermal coefficients (empirically determined), inverter specifications, ambient temperature, specified thermal load, and flow rate. We have analyzed the variance between actual data and the model output over hourly, daily, weekly and monthly periods to identify any sources of discrepancy. We have refined the model as needed and utilized it in the further task elements below.
- Assessed the directly measured energy production totals and their economic value based on Pt. Hueneme's and PRFTA's actual energy rates. We have compared these results with the performance objectives in (i) absolute terms and (ii) relative terms with PV and SHW reference designs. (PO2)
- Assessed GHG reduction based on actual energy production, analysis of offset energy resources, and a pre-existing life cycle analysis that accounts for manufacturing and installing the solar array; including validation of the GHG reduction relative to site baseline and compared to conventional PV and SHW reference designs. (PO3)
- Demonstrated successful remote monitoring of performance and system health; documented operational and maintenance requirements. (PO6)
- Verified tracking accuracy over time (via built-in inclinometers) and the reliability of the motion mechanism. (Note: these tolerances are wide since tracking occurs along a single axis, not in 2D.) (PO6)
- Measured performance degradation over time resulting from accumulation of dirt on the system ("soiling") to determine the optimal surface cleaning interval, balancing the impacts on energy production and operating cost. (Note: the anticipated schedule was one or two times per year based on experience at SWC.) (PO6)
- Determined an appropriate inspection interval (estimated: 5 years) based on the tests described above, the capabilities of the system self-diagnostics, and DoD guidelines and justify the inspection interval. (PO6)

Task 6: Prepare cost analysis and HPPA analysis

This task included:

- Prepare comprehensive life cycle cost analyses for the demonstration systems based on the final total installed cost and operating and maintenance costs over the demonstration period (plus projected costs).
- Project the analyses for future systems of the same type, based on an analysis of the bill of materials together with documented vendor quotes for materials when purchased in higher quantities.
- Prepare simulated comprehensive life cycle energy price and investment return analyses for the demonstration systems as if they were financed and built by private investors through an HPPA arrangement able to capture tax credits and other incentives not available to a system acquired directly by The DoD.[1]
- Compare the analyses listed above with similar cost analyses of the reference PV & SHW systems. (PO4).
- Generalize the model to future systems for The DoD including variables such as location, utility rates (including tiered and time-of-use rate structures), hot water consumption profiles, and incentives and tax credits.

Task 7: Prepare reports and present results

Cogenra has prepared final cost and performance reports in order to rigorously document performance and cost parameters for solar cogeneration systems engineered to military specifications. The results add to the findings of previous case studies obtained in civilian commercial and industrial settings.

5.2 BASELINE CHARACTERIZATION

As described in the demonstration plan and test design, Cogenra installed meters to measure the hot water consumption at each of the five buildings in the demonstration project. Measurements began as early as October 2012.

Extensive results of the baseline hot water usage metering at each building are presented in Appendix B. Examples of some of the results of the baseline characterization are given below for the Kitchen at Port Hueneme. Table 2 shows a simple summary of the typical measured hot water usage at each building, in gallons per day. Hot water gallons/day usage is one of the most important parameters for evaluating the hot water demand—and thus the potential benefit of a solar hot water or cogeneration system—at a site.

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[1] We did not propose to set up the demonstration projects as HPPAs because of the anticipated complexity of acquisition related issues in the context of an ESTCP-funded project. A key objective of the demonstrations is to generate validated results at DoD sites to help secure private investment in future systems arranged as HPPAs.

Table 2: Summary of typical hot water usage in gallons/day (GPD) as measured for each building. Detailed results are given in Appendix B.

Project Site	Typical Measured Hot Water Usage [GPD]
Port Hueneme, Bldg 61 Kitchen	2500 – 3500
Port Hueneme, Bldg 1481 Barracks	300 – 1200
Port Hueneme, Bldg 1517 Barracks	5900*
PRFTA, Kitchen	1500 – 2000
PRFTA, Barracks and Laundry	60 – 300

** Partial measurement; see appendix for details*

An important result from Table 2 is that how water demand varied widely among the five buildings in the demonstration project. Two of the barracks buildings (Port Hueneme Bldg 1481 and PRFTA Bldg 394) had especially low or inconsistent hot water usage. Hot water demand directly impacts how much useful energy a solar hot water system can deliver, and the inconsistent usage at some of the buildings in the demonstration project means that the cogeneration systems were not fully utilized at these sites.

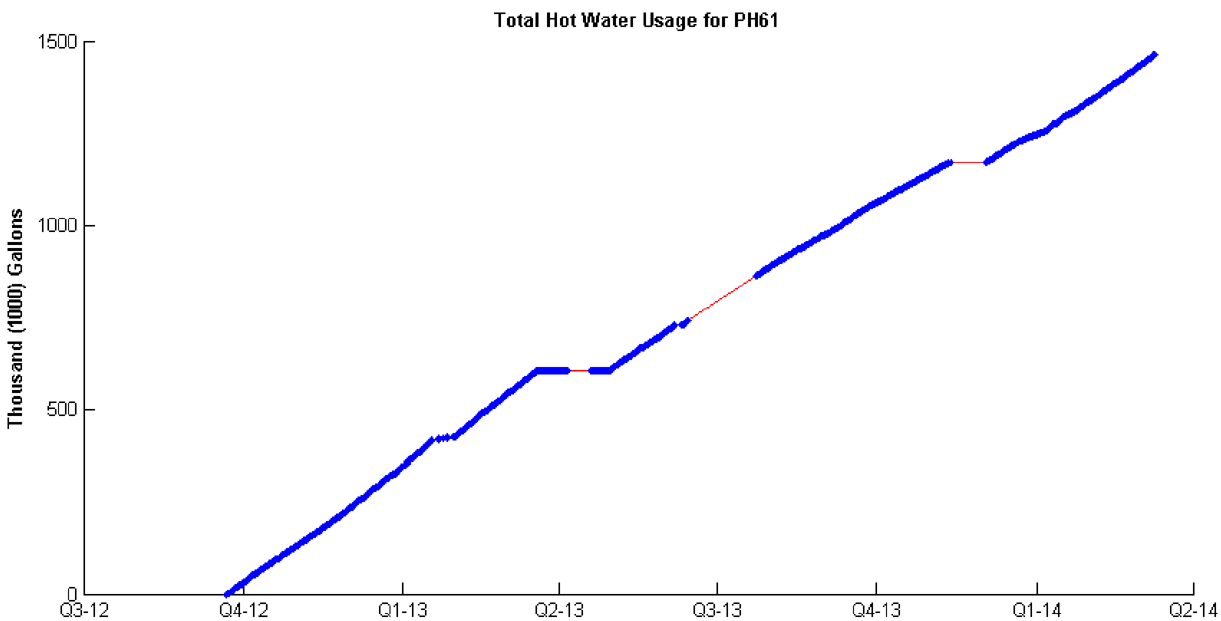


Figure 8: Total (cumulative) customer-side hot water usage at Port Hueneme, Building 61. Red lines show interpolated points. This building, the galley, showed very consistent hot water usage during most months.

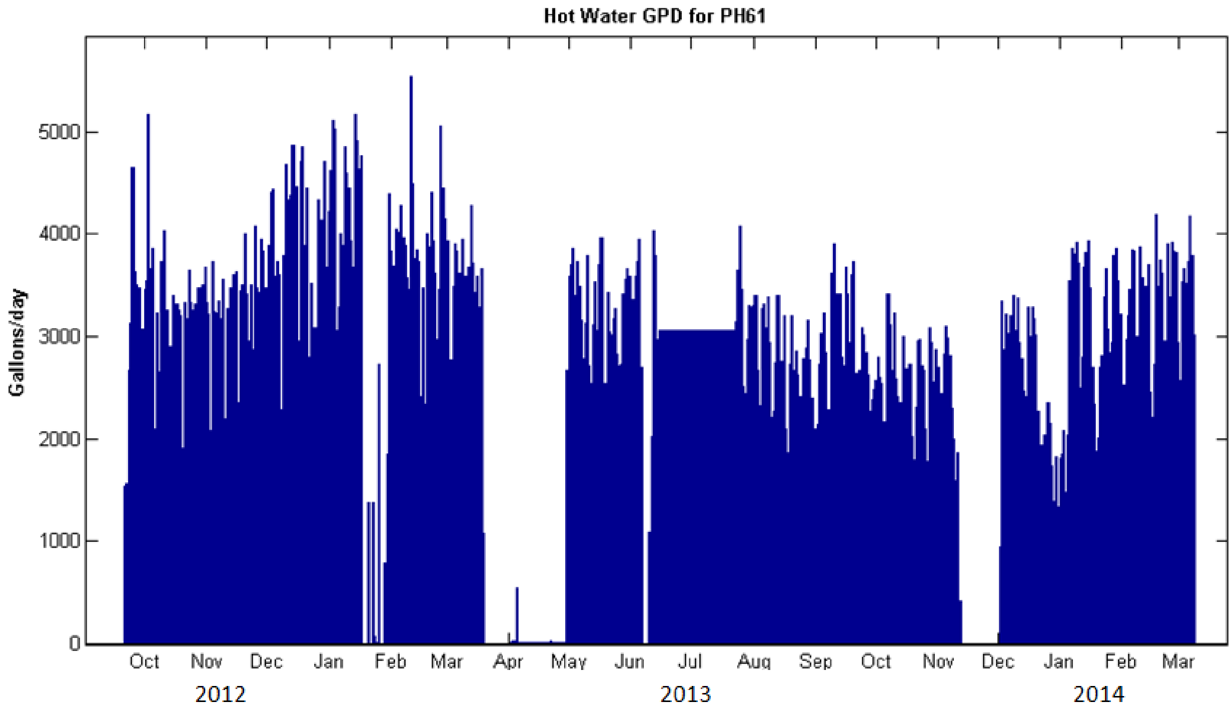


Figure 9: Hot water usage per day at Port Hueneme, Building 61. Hot water gallons/day usage is one of the most important parameters for evaluating the hot water demand—and thus the potential benefit of a solar hot water or cogeneration system—at a site.

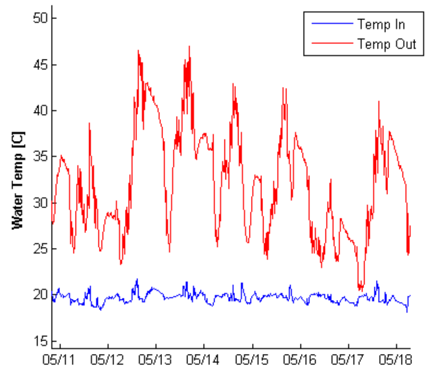


Figure 10: Sample data of hot water inlet and outlet temperatures at Port Hueneme, Building 61.

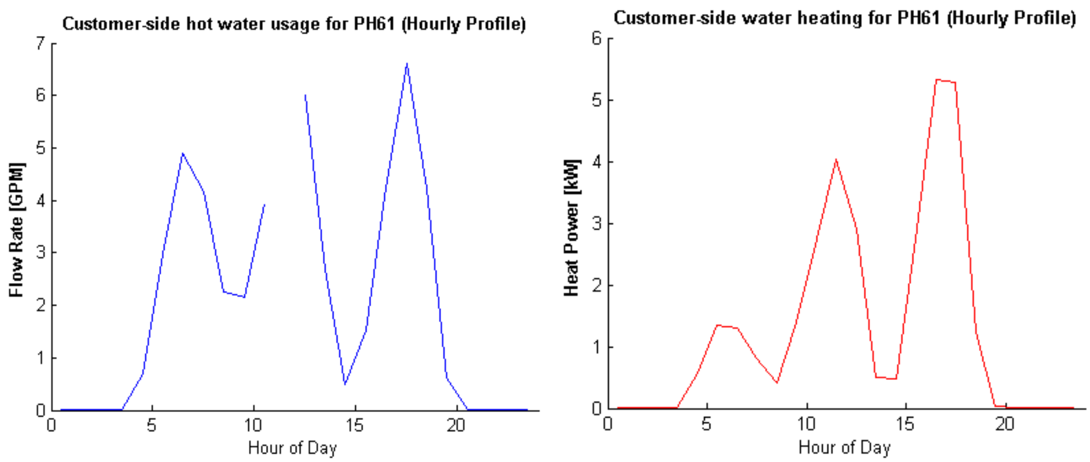


Figure 11: Daily hot water usage profiles, for Port Hueneme, Building 61. All days with measured hot water usage were combined with an hourly average to determine the typical daily profile. This example clearly shows three peaks corresponding to the three meals per day at the galley.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Cogenra's SunDeck solar collectors are water-cooled concentrating PV (CPV) parabolic troughs that capture rather than dissipate what other PV approaches call "waste heat." The architecture comprises a series of arrays that independently track the sun along one axis. Within each array, a series of flat mirrors concentrate sunlight (~8X) onto silicon-based PV-Thermal (PVT) panels that generate electricity. Conduits extruded directly through the panel back-plate carry a water-glycol mixture in a closed loop that cools the PV cells, enhancing their performance, and captures the excess solar energy as heat. A compact SHW heat exchange/storage system transfers the heat to preheat the domestic water supply before it enters the site's pre-existing hot water heater.

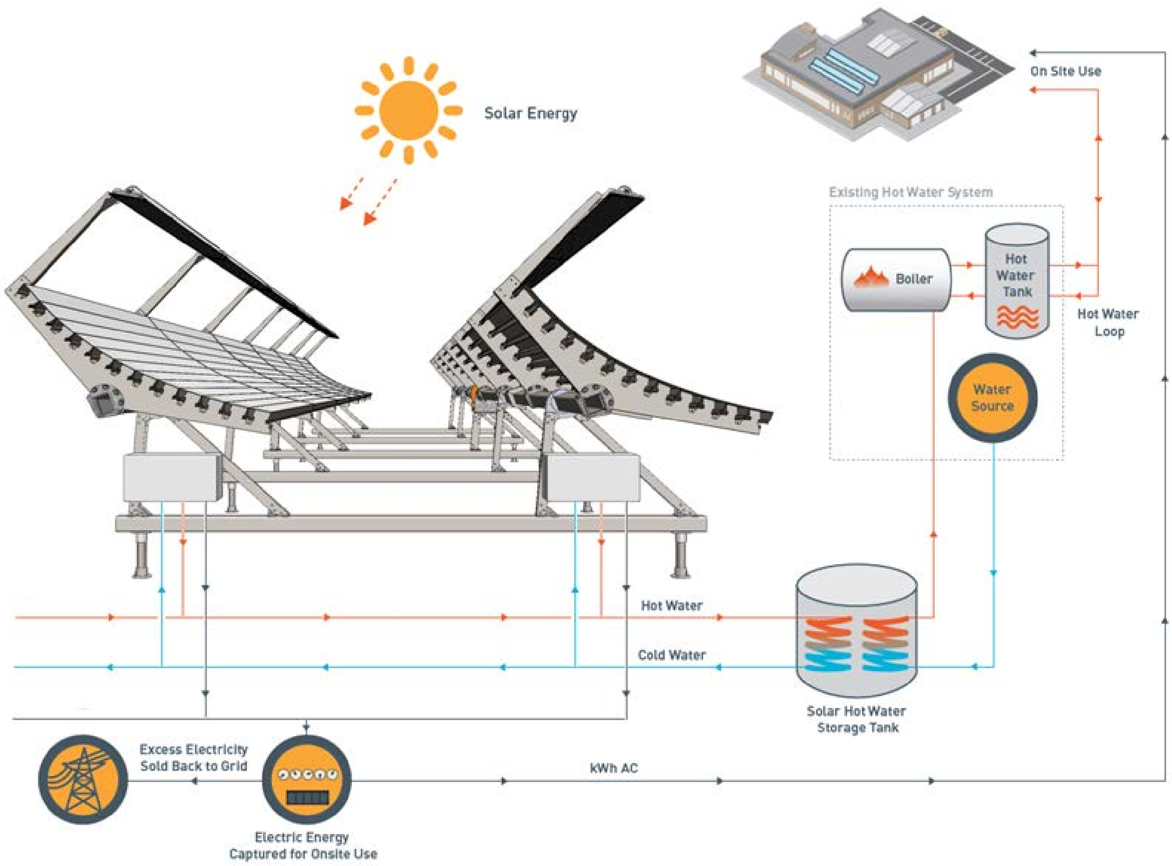


Figure 12: Typical system configuration

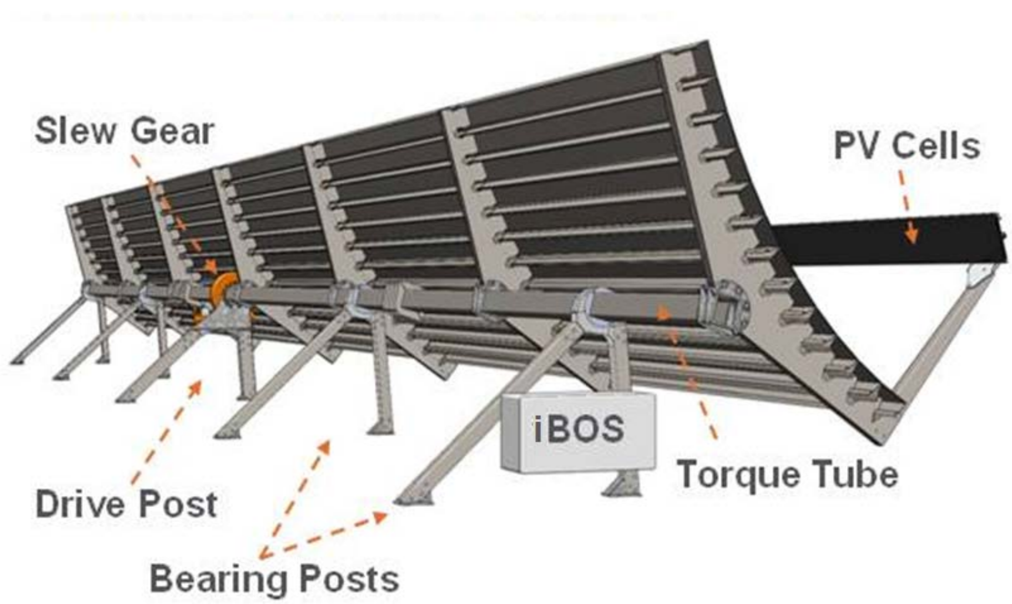


Figure 13: System components, back side

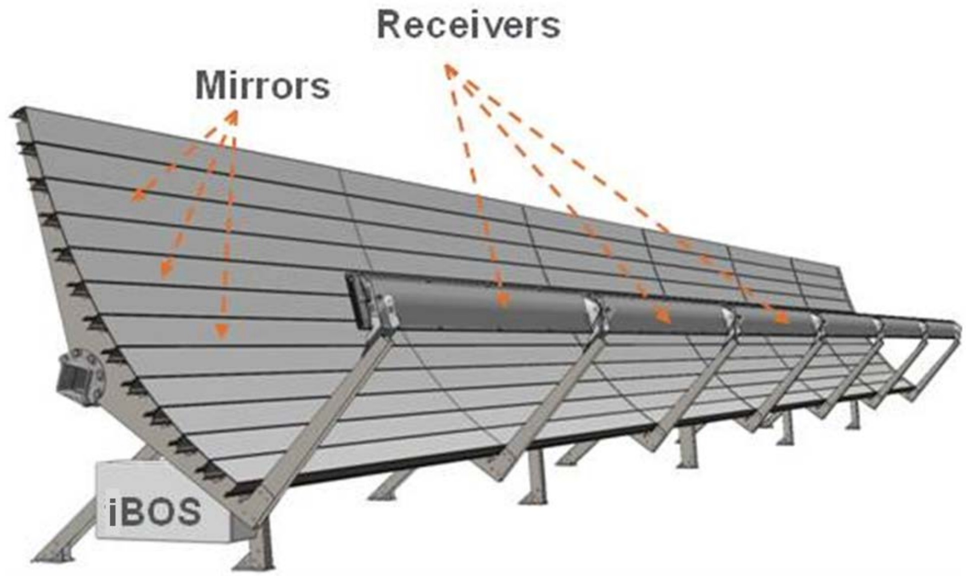


Figure 14: System components, front side

Each roof-mounted SunDeck module comprises one half-parabola that focuses onto a single PVT panel mounted above the mirrors along the focus line. The module axis can be oriented in any orientation, and the module pivots around that axis to track the sun. This configuration enables a much lower profile, lower wind loading, and lighter weight (5 psf total) than the ground-mounted SunBase, and is suitable for nearly all types of roofs with a pitch of up to 20°.

The only components that are added at an installation are the SunDeck systems, a hot water storage tank, an electrical connection to the buildings circuit breaker, and plumbing connecting the SunDeck to the storage tank, the city water supply to the solar storage tank, and the storage tank to the existing hot water tank. Installations are set up so that the SunDeck is connected to the storage tank with an isolated closed heat transfer loop. The storage tank gets fresh water from the city water supply; hot water from the storage tank is then supplied into the inlet of the existing hot water tank. No existing infrastructure needs to be removed.

Each SunDeck includes a small control box that receives input from a number of sensors and can control the position and water flow rate of the SunDeck. This control unit also relays data back to central servers to allow for monitoring of the system. Positioning of the system is controlled through a combination of an angle sensor and proprietary sensor designed to monitor to the position of the light on the receivers and ensure that it stays centered. Water temperature is controlled by three temperature sensors and a flow sensor. There is one temperature sensor on the cold water supply and one on the hot water exit. Combined with the flow sensor this allows the SunDeck to ensure that the hot water is exiting the system at a set-point temperature if

desired, regardless of the input temperature and how much sun there is. The third temperature sensor is on the last receiver and is there to make sure that the water in the receivers does not get too hot. If it does the system will detrack and cool off.

The control box is part of the SunDeck iBOS, an integrated balance-of-systems unit. In addition to the system controller, the iBOS contains the hydronics components including the pump, flow pressure and temperatures sensors, valves and hydronic connections. The iBOS is also integrated with the photovoltaic inverter.

The demonstration project included systems at NBVC Port Hueneme and PRFTA, with five distinct arrays in total. The size of each installation and general layout are described in Section 4.1, Facility/Site Location and Operations. In order to describe a typical installation, here we present additional details on the system design at the Port Hueneme Galley, Building 61.

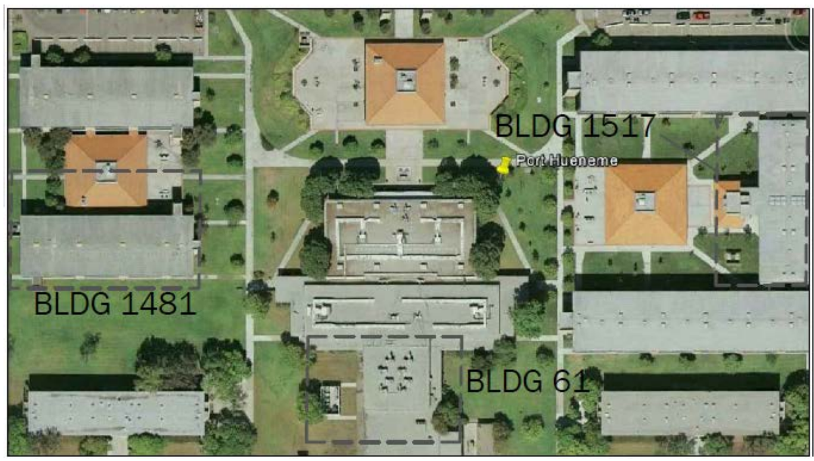


Figure 15: Port Hueneme site, including the three buildings on which SunDeck systems were installed.

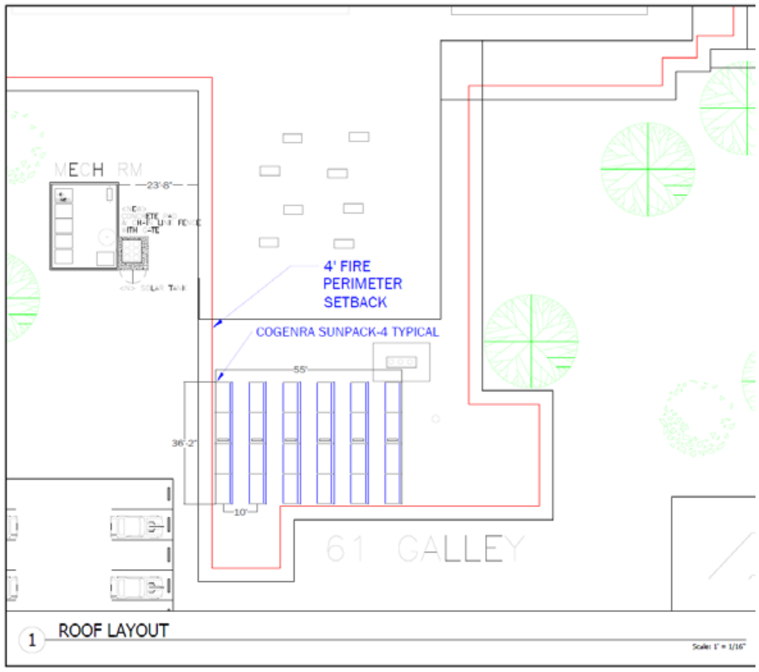


Figure 16: Roof layout at Port Hueneme Bldg. 61. The SunDeck rows are in a north-south axis orientation.

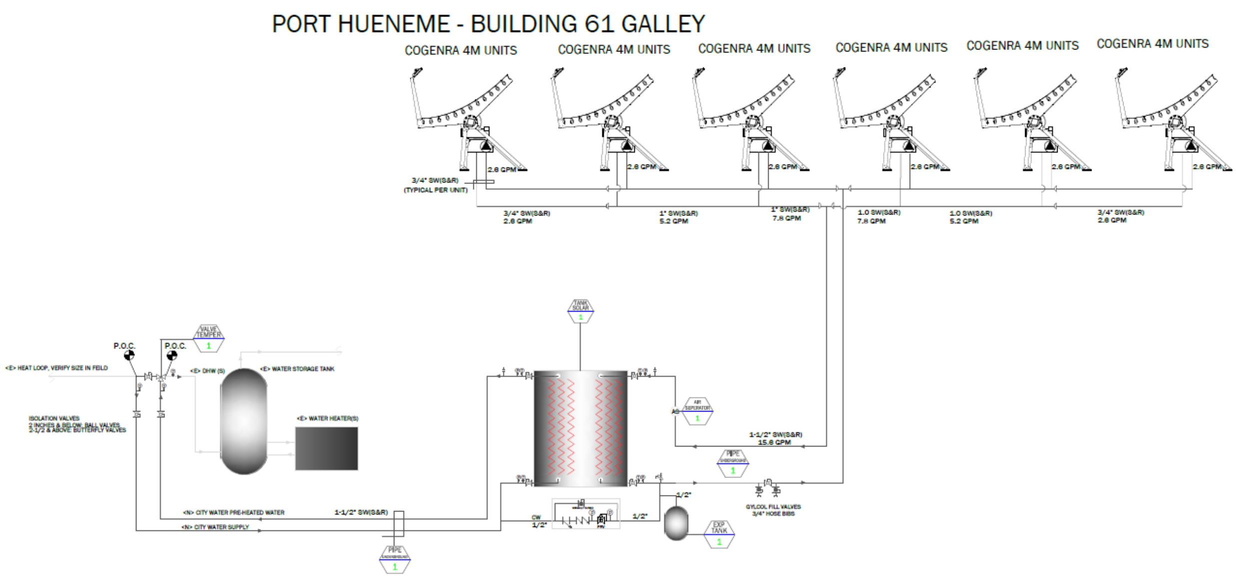


Figure 17: System hydronics configuration, including the solar tank and the existing hot water tank and heater.

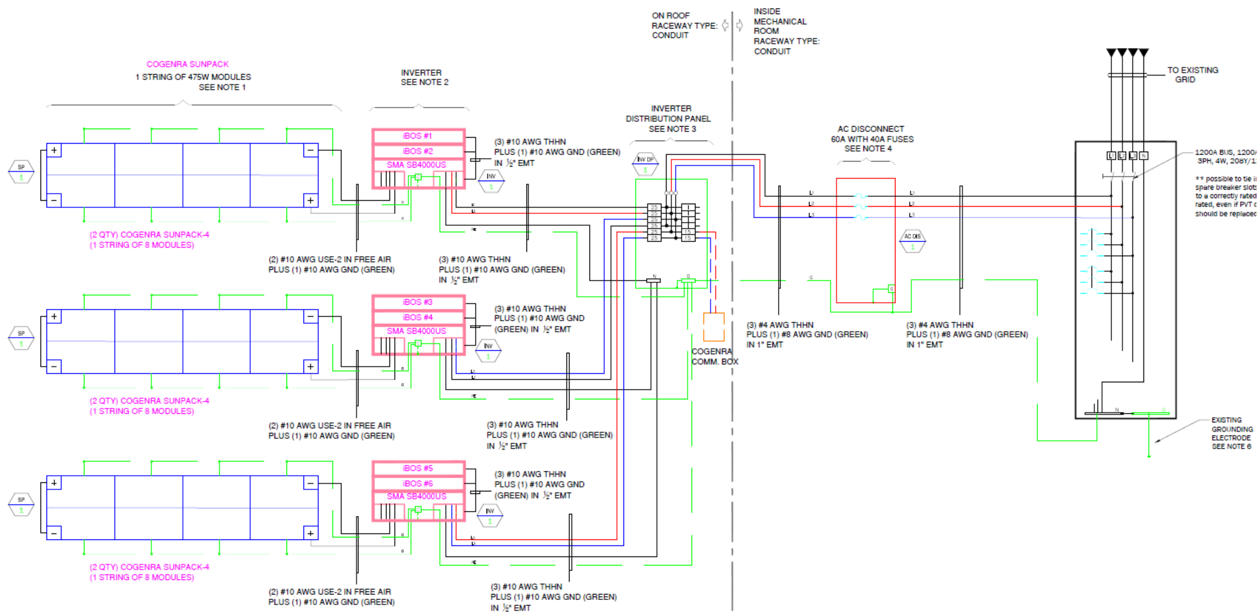


Figure 18: System electrical configuration, including inverters and iBOS (pink boxes) for each SunDeck row, inverter distribution panel, AC disconnect and grid connection.

5.4 OPERATIONAL TESTING

Data collection during operation and testing of the system is made simple as all data is automatically uploaded to a central server. Regardless of the state of the system, except of course if there is a power outage, data from all temperature sensors, flow sensors, angle sensors, proprietary positioning sensors, motor current, pump current, and a number of other parameters from the SunDeck systems are recorded. See Figure 19 for the schematic.

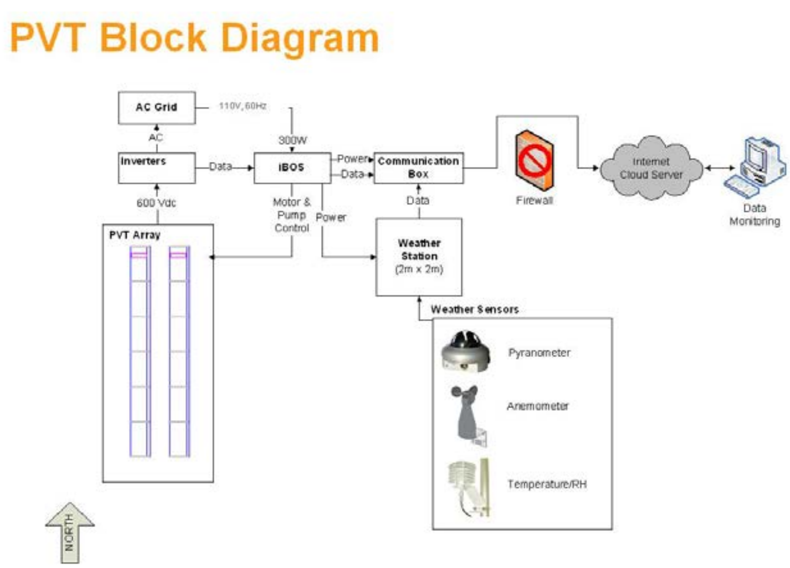


Figure 19: Schematic showing communication and control flow for the PV-Thermal array

In addition for this demonstration temperature and flow meters were installed in the demonstration buildings. Data from these sensors are recorded and uploaded to a central database. This continuous data collection allows Cogenra to monitor and assess the performance of the system during all operating conditions.

This demonstration project also included weather stations at each of the two locations. These weather stations measure solar irradiance, ambient temperature and wind speed.

The data collected can be compared to a sophisticated predictive model that Cogenra has developed. The model predicts the PV and thermal outputs of the system based on the system dimension, calculated sun angle, measured irradiance, mirror reflectivity and PV response of a typical receiver (previously measured in the laboratory), various thermal coefficients (empirically determined), inverter specifications, ambient temperature, wind velocity, specified thermal load, and flow rate.

The actual dates and duration of the operational testing are shown in Figure 10, the complete project schedule.

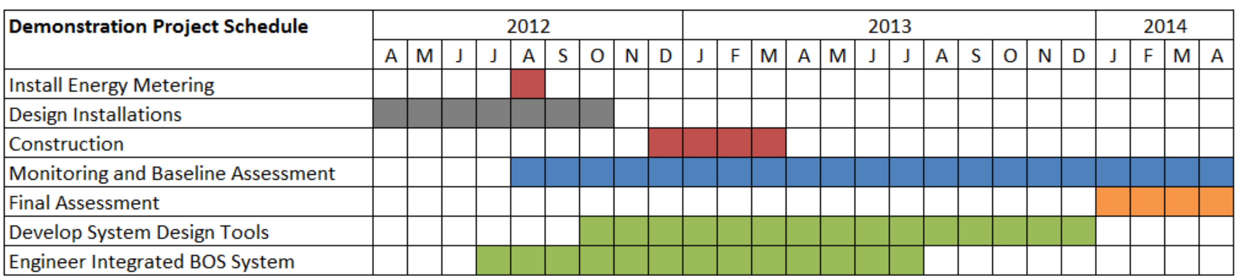


Figure 20: Project schedule, including all phases of operation and testing

Once the demonstration is finished the systems can continue operating for more than 20 years. During this time very little maintenance is required and much, if not all of it can be performed by facility staff. Operations and maintenance of Cogenra's SunDeck system is fairly minimal and thus requires very little training. The systems have built in diagnostics that will alert the system owner if maintenance is needed. The owner can also monitor performance online. The following preventative maintenance items are recommended, although they are not necessary if power output continues to meet expected design parameters:

1. Annual visual inspection of the system. (No special training is required.)
2. Mirror washing during the dry months may be indicated. The rate at which dirt accumulates and the degree to which rain removes the dirt depends on the site. Cleaning the mirrors requires only a garden hose, a squeegee mounted on a handle, and a lint-free cloth. The mirrors should be cleaned when the value of energy recovered as a result of cleaning exceeds the cost of cleaning. No special training is required to clean the mirrors

and the instructions are easy to follow. (Note that the power output model includes a nominal degradation factor to account for average accumulation of dirt, and the economic return model includes the anticipated cost of hiring an outside contractor to perform periodic cleanings.)

3. Comprehensive inspection of the system every five years, including testing of the glycol solution. This should be performed by a trained technician, but the system owner can perform all tests (the freeze point test requires a hand held refractometer, which costs ~$150). Technician certification takes about a half day. Cogenra's system incorporates features that prevent stagnation. The glycol solution will likely not need to be replaced during the lifetime of the system. However, testing every five years is recommended to ensure freeze protection.

5.5 SAMPLING PROTOCOL

Data is continuously collected from all sensors installed in the demonstration buildings and integrated into the SunDeck systems. These sensors automatically record data averages on five-minute intervals, and then this data is uploaded to a central database. A list of all important sensors or measurements is given in Table 3 .

Table 3: List of measurements

Sensor or Measurement	Location or Multiplicity	Data Logging
Direct Normal Irradiance	Weather station at each site	5 minutes, 24/7
Diffuse Horizontal Irradiance	Weather station at each site	5 minutes, 24/7
Ambient Temperature	Weather station at each site	5 minutes, 24/7
Wind Speed	Weather station at each site	5 minutes, 24/7
Glycol solar loop inlet and outlet temperatures	Each SunDeck row and array	5 minutes, 24/7
Glycol solar loop flow rate	Each SunDeck row and array	5 minutes, 24/7
Domestic hot water flow rate	Each system (each building)	5 minutes, 24/7
PV Imp, Vmp, Pmp DC, Pmp AC	Each inverter	5 minutes, daytime
Tracker angle	Each SunDeck row	5 minutes, 24/7

5.6 SAMPLING RESULTS

As described in the sampling protocol above, the Cogenra systems include a wide range of sensors that record data on five-minute intervals. An example of the type of data recorded for each Cogenra system is shown in Figure 21, as viewed using one of Cogenra's proprietary in-house data monitoring tools.

Figure 21: Example of two days of 5-minute sampling data as viewed using one of Cogenra's proprietary in-house data tools. Data shown is for a system at Port Hueneme, Building 61 (Galley).

6 PERFORMANCE ASSESSMENT

1) Increase renewable energy delivered per unit area.

The electrical and thermal energy converted by each SunDeck array was measured throughout the course of the demonstration. Performance Objective #1 specifies that this energy shall be compared to what a reference flat-panel PV array would produce for the same area. The key criterion for success was to produce 475%, or 4.75x the energy of the reference standard PV array.

The output of the reference PV system was simulated using industry-standard PV performance modeling methods, based on the actual measured solar irradiance and ambient conditions measured by Cogenra's weather stations at each site. PV performance results were validated against industry-standard modeling tools including PVsyst and NREL PVWatts. Additionally, one reference fixed-tilt PV panel was installed at each base alongside the Cogenra system, and the power output was measured continuously. This allowed for excellent validation of our comparison to standard PV.

A full year of energy output data was used to evaluate the system performance with respect to Performance Objective #1. The plots below show a sample of the results for each of the five installations, showing results from May and/or June 2013. In addition to the Cogenra system (measured) and reference PV system (simulated with measured validation), results are also shown for an analogous reference solar hot water (SHW) system.

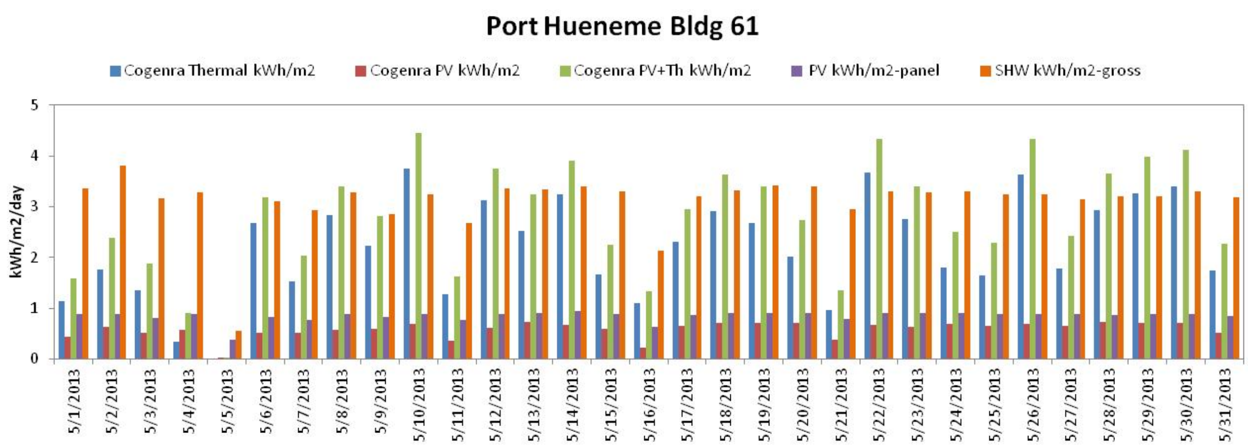


Figure 22: Cogenra system PV and thermal energy output per square meter per day, along with reference PV and SHW systems, for Port Hueneme Galley.

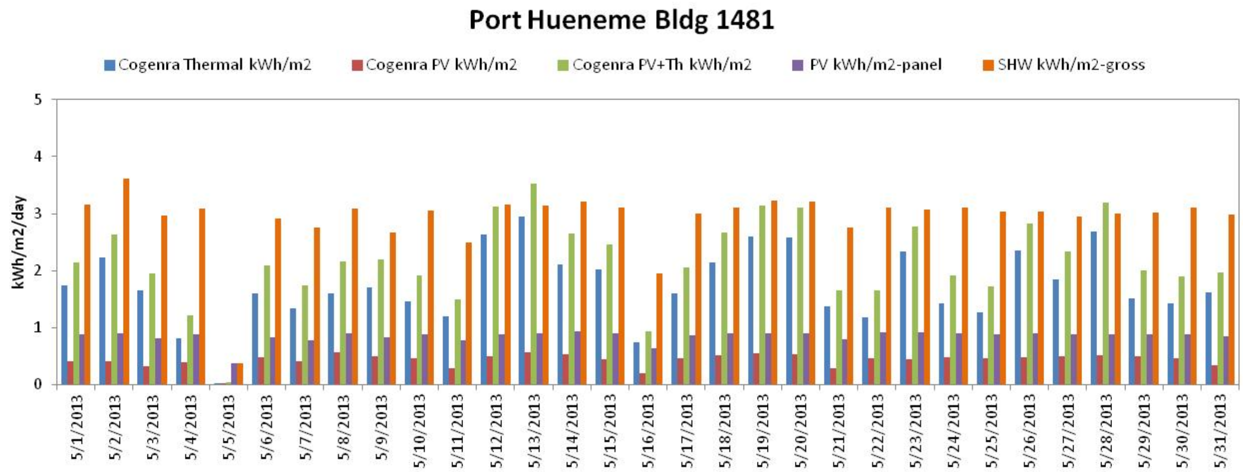


Figure 23: Cogenra system PV and thermal energy output per square meter per day, along with reference PV and SHW systems, for Port Hueneme Barracks 1481.

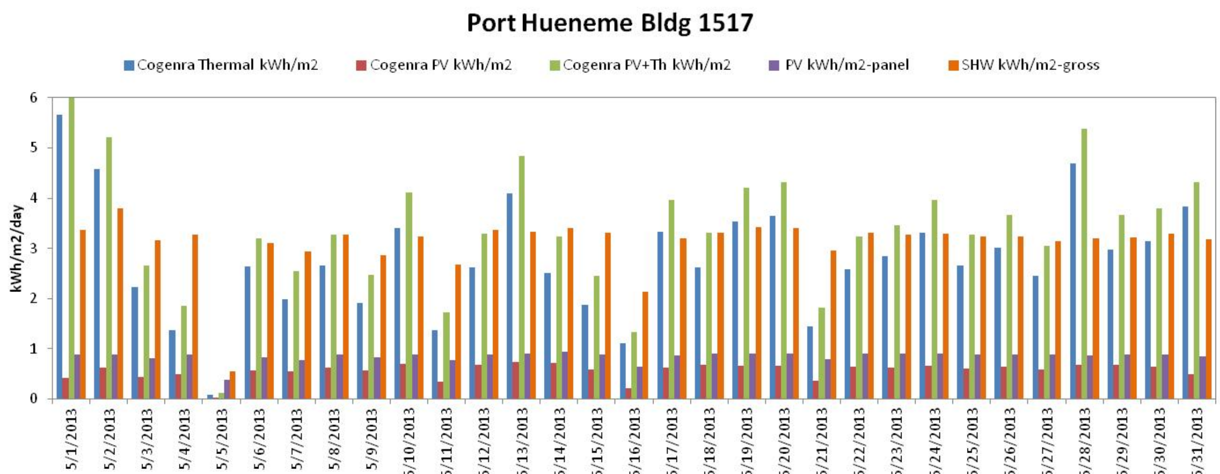


Figure 24: Cogenra system PV and thermal energy output per square meter per day, along with reference PV and SHW systems, for Port Hueneme Barracks 1517.

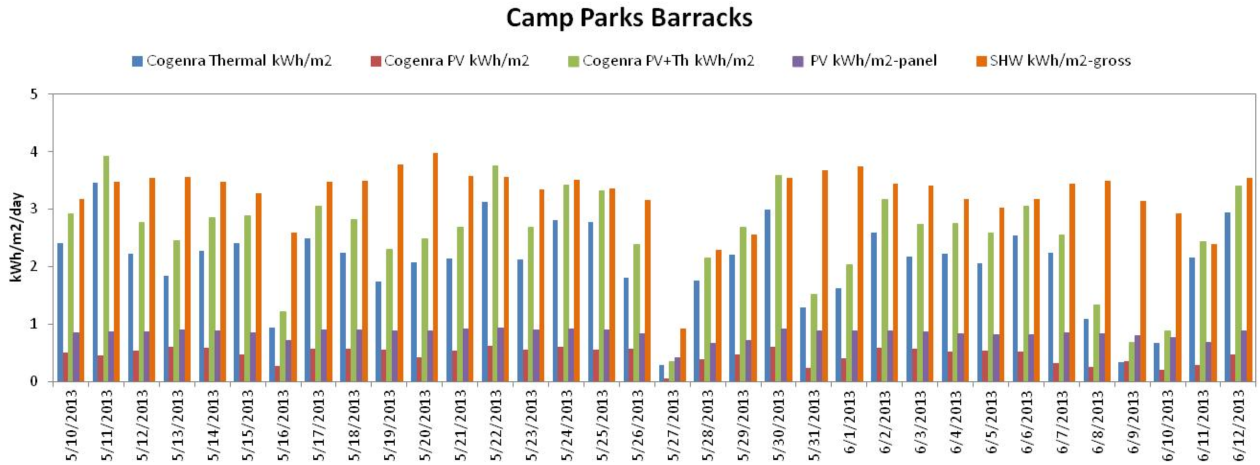


Figure 25: Cogenra system PV and thermal energy output per square meter per day, along with reference PV and SHW systems, for PRFTA Barracks.

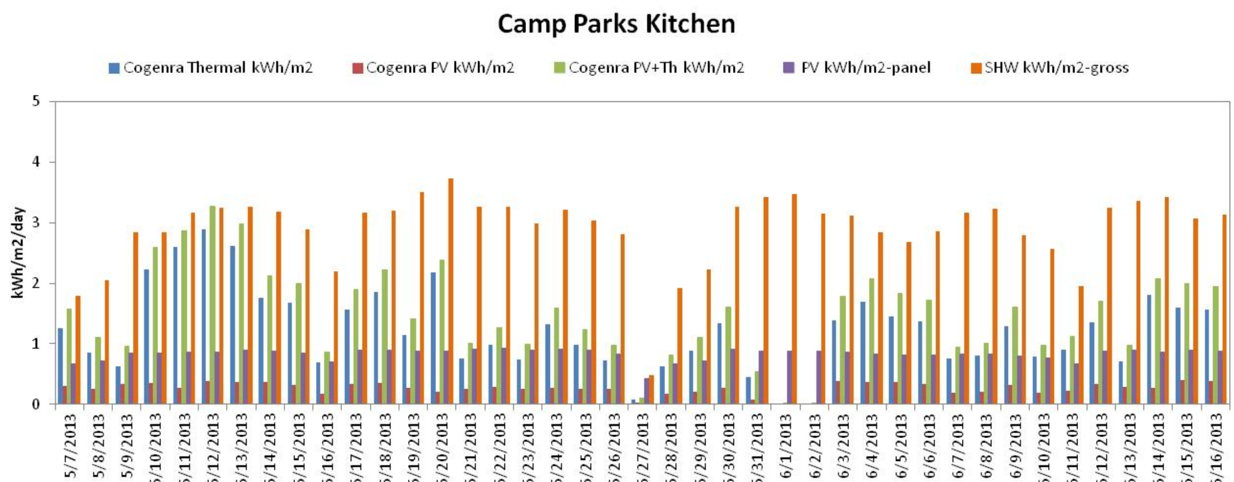


Figure 26: Cogenra system PV and thermal energy output per square meter per day, along with reference PV and SHW systems, for PRFTA Kitchen.

Additionally, a full year of monthly output is summarized in the tables below. The tables show results from two of the installations at Port Hueneme.

Table 4: Monthly output table for Port Hueneme Bldg 1481 (Barracks)

That system has 24 modules, each one 3.5m2 oriented E-W

Time Period	Electricity [kWh]	Heat [kWh]
Apr 2013	281	304
May 2013	1143	4550

June 2013	641	2892
July 2013	478	2390
Aug 2013	535	2371
Sept 2013	522	2086
Oct 2013	522	2088
Nov 2013	519	2076
Dec 2013	713	2852
Jan 2014	596	2324
Feb 2014	474	1872
Mar 2014	722	2852

Table 5: Monthly output table for Port Hueneme Bldg 61 (Galley)

That system has 24 modules, each one 3.5m2 oriented N-S

Time Period	Electricity [kWh]	Heat [kWh]
Apr 2013	305	1220
May 2013	1537	5765
June 2013	714	3703
July 2013	437	2186
Aug 2013	734	2867
Sept 2013	866	2841
Oct 2013	555	1805
Nov 2013	102	461
Dec 2013	*Building power surge knocked out communication	
Jan 2014		
Feb 2014	134	549
Mar 2014	529	2090

A summary of the important results is given in Table 6 . Normalized per year and per unit area, the Cogenra systems delivered 408% the renewable energy of the reference PV array. The total energy was 825 kWh/yr/m^2. The corresponding success criteria laid out in the demonstration plan were 475% and 935 kWh/yr/m^2. The energy delivered by the systems was limited by

inconsistent hot water usage at some of the buildings, preventing the full utilization of the cogeneration system. This is the main reason identified for observed performance that is slightly short of the target set in Performance Objective #1. Adequate and regular heat usage is essential for fully realizing the benefits of any system that includes solar water heating. In general, we observed that hot water usage was particularly inconsistent at the barracks, which were not always occupied. Hot water usage at the kitchens was more consistent. Detailed results on hot water usage are provided in the "baseline profile" sections. Further analysis and explanation follows below.

Table 6: Summary of energy output vs. reference PV array

Cogenra thermal output	657 kWh/yr/m^2
Cogenra PV output	168 kWh/yr/m^2
Cogenra PV + thermal = total energy	825 kWh/yr/m^2
Reference PV array	202 kWh/yr/m^2
Cogenra/PV total renewable energy	**408% vs. Standard PV**

A solar thermal system can only deliver, at maximum, as much heating as the customer actually uses. When hot water usage is low, the domestic hot water loop draws less heat energy from the solar loop than the system has the capacity to provide. This causes the solar tank to increase in temperature. In this way, the solar tank provides valuable hot water storage. However, as the tank heats up, the solar array is able to add less and less heat. This is because the thermal efficiency of any solar thermal collector decreases with temperature due to heat losses.

Figure 27 and Figure 28 illustrate the effect of inconsistent hot water demand at the PRFTA Barracks. Figure 27 shows the temperature reached by the solar fluid loop for each day throughout the spring and summer of 2013. The temperature exceeded 60°C (140°F) on many days, a high temperature for a domestic hot water system. *This high temperature is a direct consequence of the hot water demand in the building, and directly limits the performance of the solar array.*

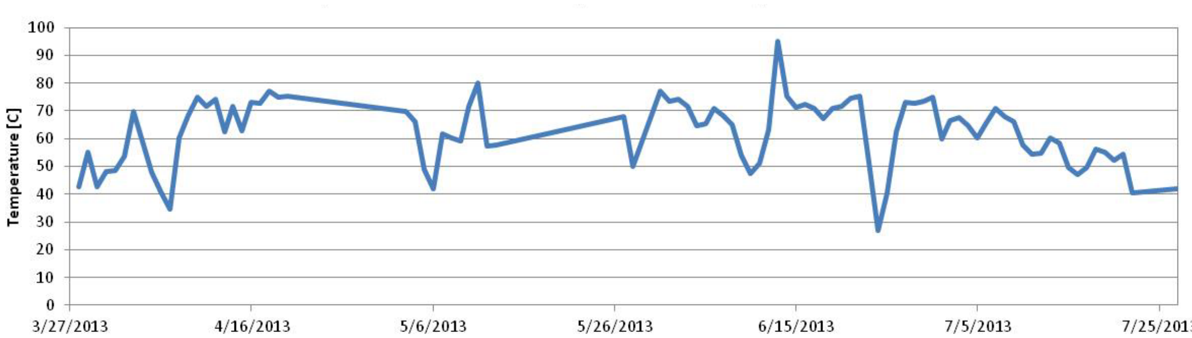


Figure 27: Daily maximum solar-loop fluid temperatures at PRFTA Barracks

The second figure plots the electrical and thermal output of a SunDeck row at the PRFTA Barracks for two days, and clearly shows how system performance was limited by low hot water usage. In the morning, the solar tank is cold and the array delivers both heat and electricity at its full capacity. As the day progresses, if hot water usage is inadequate, the temperature of the solar tank rises and the system is able to add less and less heat. In this situation, *the system continues to perform properly, but the thermal energy output is limited by how much the customer is using*. In some cases, if the fluid temperature reaches 70°C (158°F), the system will "de-track", i.e. move off sun temporarily to avoid overheating. (This de-tracking ability is an advantage of the Cogenra system, compared to traditional SHW collectors that often struggle to survive "stagnation" scenarios.)

In summary: The SunDeck systems performed well and delivered over 4x as much energy as a reference PV array, but some of the systems were not fully utilized due to inconsistent hot water demand. This resulted in energy output slightly short of the 4.75x target in Performance Objective #1. Although it is difficult to model precisely, our analysis suggests that under-utilization contributed to overall performance reductions of 10-15% for PV and 20-30% for water heating.

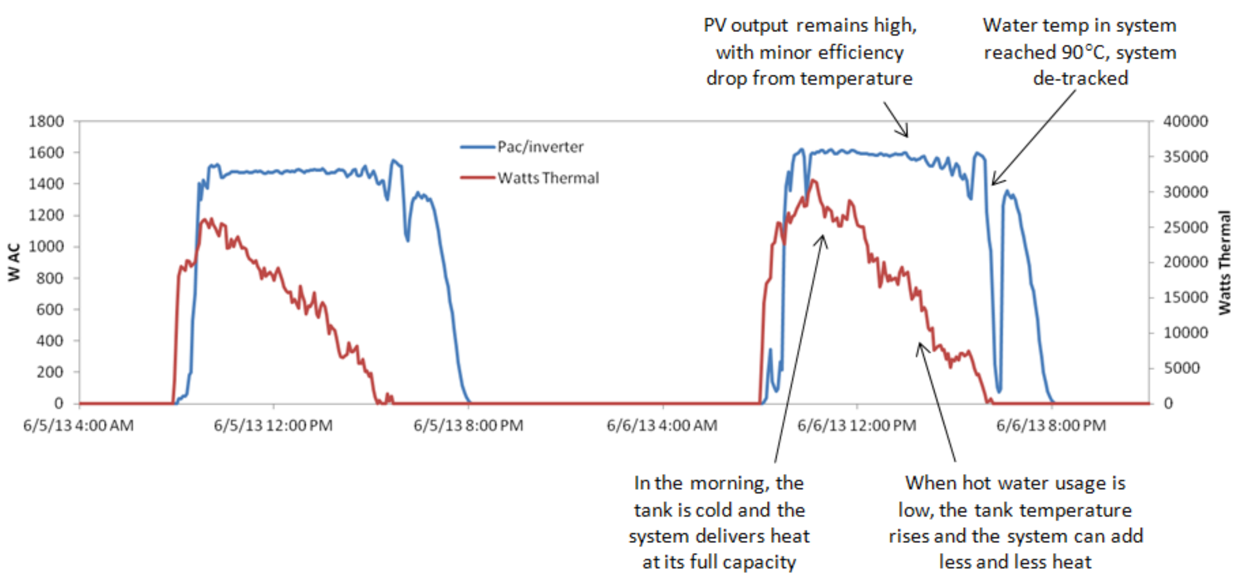


Figure 28: Electrical and thermal output for a SunDeck row at PRFTA Barracks, clearly showing the impact of low or inconsistent hot water usage.

2) Increase renewable energy economic value per unit area.

Objective #2 refers to the *economic value* of the renewable energy delivered by the system, and thus combines the energy results from Objective #1 with the utility rates paid by the customer. To determine energy savings and economic value, one must consider the energy usage that was offset by the renewable energy delivered. In the case of electricity, the electricity offset simply equals the electricity delivered. With water heating, the gas boiler (water heater) efficiency must be taken into account. Each therm of heat delivered by the solar array directly heats the water. A therm of natural gas heats water by a lesser amount, namely the boiler efficiency. A therm or kWh of heat delivered by the solar array thus offsets a greater amount of natural gas or other fuel that would have been required to provide the same water heating.

Table 7 summarizes the energy value delivered by the Cogenra system, along with reference PV and SHW arrays in the same location. The energy costs assumed are \$0.13/kWh for electricity and \$0.82/therm for natural gas (including delivery), which are representative of the rates paid by the bases. Typical boiler efficiency of 80% is used.

Table 7: Summary of energy economic value vs. reference PV and SHW arrays

	Array Energy Delivered [kWh/yr/m^2]	**Energy Offset [kWh/yr/m^2]**	**Energy Value [\$/yr/m^2]**
Cogenra thermal output	657	821	\$23.00
Cogenra PV output	168	168	\$21.82
Cogenra PV + thermal = total energy	825	989	\$44.82
Reference PV array	202	202	\$26.28
Reference SHW array	915	1144	\$32.01

Assumptions: electricity at \$0.13/kWhr, natural gas at \$0.82/therm (including delivery), boiler efficiency 80%

The results show that the Cogenra system produced 171% of the value of the reference PV array and 140% of the value of the reference SHW array. (Note that if the solar heat is displacing electricity as in some installations, the value from the Cogenra system would be \$107.25/yr/m^2, 408% of the reference PV array.)

Although the Cogenra demonstration system provided much greater economic value than the reference PV or SHW arrays, the gain was less than the goal of 200% stated in Performance Objective #2. The primary reason for the difference was the inconsistent hot water usage at some of the buildings, especially the barracks. Discussion and analysis of the impact of hot water demand is given in the discussion of Performance Objective #1 above. Inconsistent hot water demand limits the utilization of the cogeneration system overall, but especially the amount and value of the heat delivered. This is why the value added with respect to the reference system was less in the case of water heating than electricity generation, in this demonstration project.

3) Reduce GHG emissions with a larger benefit per unit area.

Life Cycle Associates (LCA), an independent consulting firm specializing in life-cycle greenhouse gas analysis, studied the Cogenra system by convolving its system's solar production

with the GHG intensity factors of the offset energy sources, factoring in the "upstream emissions" associated with manufacturing and installing the system. The results of this study are shown in the figure below:

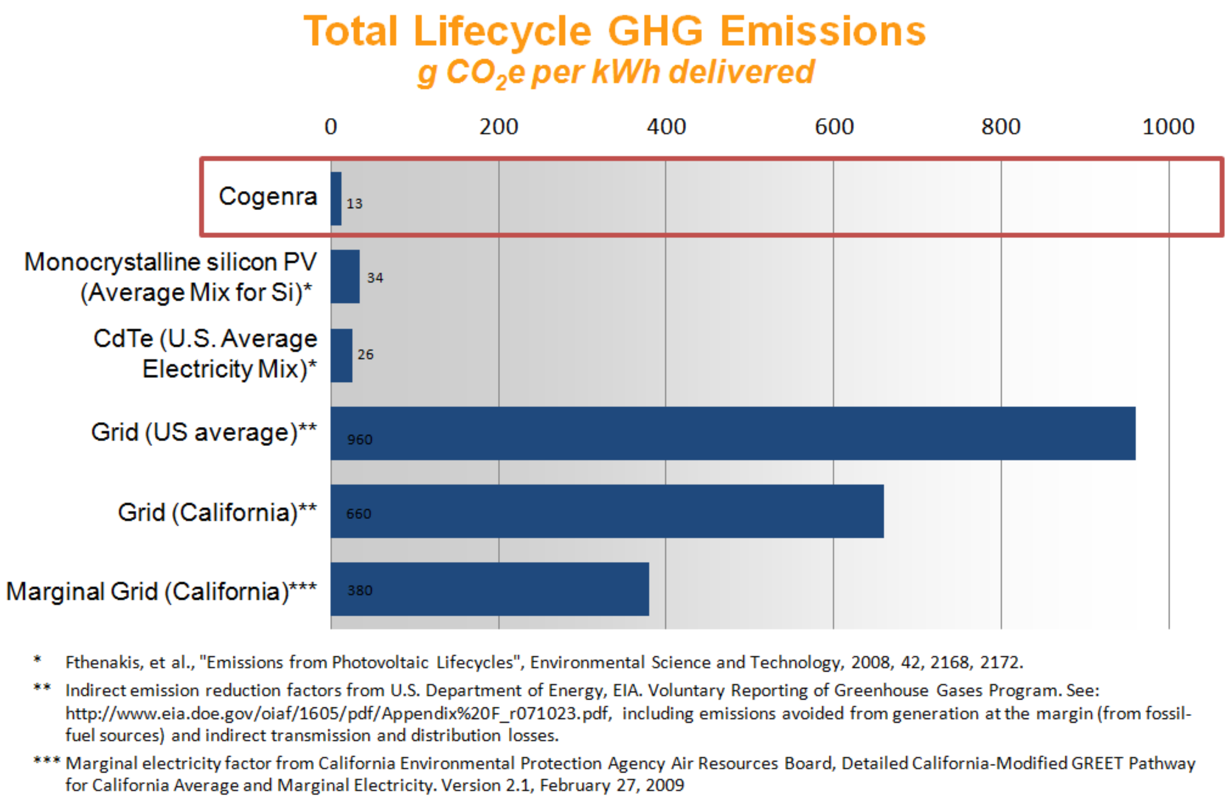


Figure 29: Lifecycle GHG emissions analysis performed by Life Cycle Associates

Solar Cogen vs. PV: Compared with a single-axis tracked PV system with the same type of solar cells and the same collection area, Cogenra's system produces approximately 5X the total renewable energy — the same amount of electricity and in addition 4X that much energy as hot water. Taking into account the relative carbon intensities of generating electricity and heating water, the overall advantage works out to 2.6X. That is, a Cogenra system occupying one acre achieves the same GHG offset as a tracked PV system that occupies 2.6 acres.

Solar Cogen vs. SHW: A fair comparison between solar cogen and solar hot water is more difficult because SHW systems are usually much simpler and do not track the sun. A SHW system that tracks the sun could in theory produce about the same total energy as a Cogenra system of the same size. The Cogenra system would nonetheless offset at least 1.3X more GHG emissions because generating electricity by conventional means incurs higher carbon intensity than heating water. In practice, SHW systems do not usually track the sun, so they produce less

energy and Cogenra's advantage will thus be higher than 1.3X. How much higher depends on the details of the system configuration.

The GHG reductions of a solar cogeneration system continue to accrue every year the system remains in service. Over the 25 year nominal life of a Cogenra system, the accumulated equivalent reductions are substantial.

Table 8: Equivalent ways to express carbon emissions offset by a 500kW integrated electric and thermal Cogenra system. Source: US EPA

Equivalent emissions offset	Annual	Cumulative (25 years)
CO2 emissions offset (metric tons)	331	8,275
Gasoline consumption avoided (gallons)	37,233	930,825
Tree seedlings planted and allowed to grow ten years	8,487	212,175
Mature forest preserved from deforestation (acres)	3.1	77.5

Combining the production data from the installations in this ESTCP project, the GHG intensity factors and the study presented above, the actual greenhouse gas emissions offset by the demonstration project are calculated and shown in the table below. The corresponding GHG offsets for the reference PV and SHW arrays are shown as well.

Table 9: GHG emissions offset by the Cogenra SunDeck demonstration system, and compared to reference PV and SHW arrays

	Array Energy Delivered [kWh/yr/m^2]	**Energy Offset [kWh/yr/m^2]**	**Net GHG Savings Intensity [g-CO2e/kWh]**	**GHG Offset [MT-CO2e/yr/m^2]**
Cogenra thermal output	657	821	216	0.177
Cogenra PV output	168	168	632	0.106
Cogenra PV + thermal = total energy	825	989	-	0.284
Reference PV array	202	202	611	0.123
Reference SHW array	915	1144	216	0.247

As shown in Table 9, the energy delivered by the Cogenra SunDeck array offset 0.284 metric tons of CO_2-equivalent emissions per year per m^2 of module area. This GHG emissions reduction was 230% of the reference PV array and 115% of the reference SHW array.

4) Reduce payback time.

The table below shows the cost and performance comparison of the Cogenra demonstrated system with an equivalent conventional photovoltaic and equivalent solar hot water system has been considered. The SunDeck cogeneration system similar to the type installed at Port Hueneme and PRFTA but with updated receivers utilizing the latest available high-efficiency cells has been considered. The energy production values are for locations similar to Port Hueneme and PRFTA with respect to solar resources.

The payback analysis incorporates solar rebates which this system would be eligible to the system owner if implemented in power purchase agreement structure. These rebates include the federal government's 30% investment tax credit (ITC) and the California Solar Initiative - Thermal program's performance based incentive (CA CSI Incentive). This CSI-Thermal incentive is available only for solar thermal technologies, not for PV systems.

The sensitivity of the system payback was evaluated with respect to various parameters: energy rates, solar resource, and hot water demand. See Table 15.

Table 10: Lifecycle costs and payback comparison of Solar cogeneration vs. reference PV and SHW

Comparison ($) — Cogenra SunDeck™ vs. PV vs. SHW						
Investment	**Cogenra SunDeck™**		**Equivalent Cost PV**		**Equivalent Cost SHW**	
Total Investment	$915,605		$258,750		$888,000	
Federal ITC (30%)	-$266,400		-$77,625		-$266,400	
CA CSI Incentive (2Yr)	-$382,353		$0		-$382,353	
Net Investment	$266,852		$181,125		$239,247	
Energy Output	***Electrical***	***Thermal***	***Electrical***	***Thermal***	***Electrical***	***Thermal***
Annual Displacement	113,219 kWh	505,440 kWh	113,219 kWh	0 kWh	0 kWh	505,440 kWh
Year 1 Financials	***Electrical***	***Thermal***	***Electrical***	***Thermal***	***Electrical***	***Thermal***
Cost Savings From Avoided Energy	$15,285	$18,109	$15,285	$0	$0	$18,109
Revenue Total	$ 33,393		$ 15,285		$ 18,109	
Operating Cost	-$ 1,800		-$ 492		-$ 1,687	
Financing Cost	$ 0		$ 0		$ 0	
Tax Benefit (+) / Liability (-)	$ 20,246		$ 25,372		$ 23,086	
Equity Cash Flow After-Tax	-$ 397,908		-$ 140,961		-$ 390,917	
Simple Payback	**5.1 Years**		**9.1 Years**		**7.8 Years**	
Equity IRR (Unlevered, After-Tax)	**15.4%**		**11.2%**		**10.1%**	

As can be seen from the table, the solar cogeneration offers the best overall payback and return on investment due to the dual energy offset savings and cost reduction from the combined implementation and installation of PV and SHW.

Comparison to PV: The SunDeck cogeneration array shows a payback of 5.1 years vs a conventional PV array with the same production showing 9.1 years of payback. Thus the solar cogeneration payback is 56% of reference PV system, significantly out-performing the success criteria of 70%. The reference PV array was sized to have the same PV production as the SunDeck systems.

Comparison to SHW: The reference SHW system has a payback of 7.8 years. Thus the solar cogeneration payback is 65% of reference PV system. The reference SHW array was sized to have the same SHW production as the SunDeck systems. The SunDeck system's thermal performance is slightly above the reference SHW success criteria of 60%, this is mainly

attributable to the usage limitations when the barracks were unoccupied as for the SHW system 100% of its output was assumed to be utilized.

5) Accelerate compliance with DoD energy/environmental goals.

The DoD's energy and environmental goals are discussed in Section 1.3 and Section 3, Performance Objective #5. For this qualitative performance objective, we summarize below how the Cogenra system contributes to reaching these goals at an accelerated rate:

DoD Goal: Produce or procure more energy from renewable resources

> → Cogenra SunDeck delivered 408% the renewable energy vs. standard PV per unit area. With sufficient hot water demand, this factor can be 5X.

DoD Goal: Reduce GHG emissions

> → The system demonstrated GHG offsets of 230% vs. standard PV based on module area.

DoD Goal: At least 30% of water heating from cost-effective solar

> → The cogeneration system provides solar water heating while sharing the system cost with the photovoltaic components.

The DoD's energy and environmental goals are diverse, and the Cogenra system can help to accelerate compliance in several ways. Overall, we believe that the results from the demonstration project as well as other Cogenra installations support a roughly 2X acceleration towards cost-effective compliance with these goals.

6) Low maintenance requirements.

Cogenra records, categorizes and tracks all service actions taken at any of our field installations, including these demonstration sites and our commercial installations. Since Cogenra's monitoring software monitors all sensors on the system as well as several additional performance metrics, most if any maintenance needs are detected easily and automatically and signaled with automated alarms. This allows for promptly detecting any issues and responding with the appropriate maintenance action. The system monitoring also helps to determine when is the best

time for “regular” maintenance, e.g. cleaning the mirrors if PV output indicates significant mirror soiling.

The automated monitoring system worked well throughout the demonstration project. Specific maintenance actions carried out at the demonstration projects are listed below. Overall, these operation and maintenance needs are comparable to typical PV and SHW systems.

PRFTA

- One mirror washing per year for the Barracks and two mirror washings per year for the Kitchen.
- Replacement of a temperature sensor that failed. Since all sensors are monitored automatically and continuously, the sensor failure was detected and fixed promptly.
- Repair of a pipe leak and subsequent refill of the water/glycol fluid.
- One SMA inverter failed and was replaced by the manufacturer free of charge.

Port Hueneme

- Replacement of a temperature sensor that failed. Since all sensors are monitored automatically and continuously, the sensor failure was detected and fixed promptly.

7 COST ASSESSMENT

7.1 COST MODEL

Table 11: Project Cost Table

Cost Element	Data Tracked During Demonstration	Estimated Cost	
		PRFTA (60 modules)	NBVC (84 modules)
Hardware capital costs	Costs for water tanks, structural materials, piping, and wiring		
	SunDeck modules	$84,000	$117,600
	Racking and structural components	$73,026	$102,236
	Tanks and heat exchangers	$24,698	$36,447
Installation costs	Labor costs	$197,295	$270,516
Engineering Design	Labor costs	$2,000	$5,000
Consumables	None	-	-
Facility operational costs	Solar plant requires no operational expense but helps reduce energy utilized in the building; i.e. enables operational savings.	-	-
Maintenance	Frequency and duration	$750	$1,050

Hardware lifetime	None	-	-
Operator training	Cogenra has trained facility staff in how to maintain the SunDeck system for many installations.	$500	$500
Salvage Value	None	-	-
Total cost		$383,219	$533,349

A summary of the demonstration project costs is shown above in Table 8. The total actual cost for the demonstration project was $915,568. The cost proposed in the demonstration plan was $882,520; the difference is partially due to the need to use union labor which was not budgeted.

SunDeck module: These are the solar cogeneration modules that convert the sun's energy into electricity and solar hot water. These modules are the basis for the demonstration project. The modules costs are based on Cogenra's sales prices for this version of the product. The module cost is in part a function of the photovoltaic cell efficiency utilized in the manufacturing of the modules and thermal rating of the modules.

Racking and structural components: The array racking includes the steel structure that supports the SunDeck modules and tracker, and which connects to the building roof.

Tanks and heat exchangers: Solar thermal systems typically include a solar tank; see the system configuration diagram in Section 5.3. The solar tanks in the demonstration project include immersed heat exchangers.

Installation costs: Installation costs include site mobilization; material transportation; installation of the modules, racking and tanks; roofing work; building electrical integration; building hydronic integration; and array commissioning. Some of the installation costs in the demonstration project were higher than projected due in part to the need to use union labor in some cases.

Engineering design: Mechanical and electrical design of the specific system to be installed on each building. Refer to the design tools in Section 8 for more information.

Maintenance: In general, approximately $300/site for a 50 kW-e installation, with basic maintenance (mirror washing, system checks) recommended twice/year.

Operator training: Cogenra has trained facility staff in how to maintain the SunDeck system for many of our >40 installations.

7.2 COST DRIVERS

Site-specific cost drivers:

- So-called "soft costs" can often vary by project and location, and include labor cost for installation, supply chain costs such as shipping components to a particular site, and permitting fees. In addition to regional variation in labor costs, whether or not the project requires union labor is also an important soft cost driver.
- Rooftop vs. ground-mount: Although Cogenra's SunDeck system is specifically designed for cost-effective installation on building rooftops, installation on the ground is usually less expensive. If ground space is available, the cost trade-offs of a rooftop vs. ground system should be weighed accordingly.
- Dust and soiling factors: Solar PV and SHW modules are subject to the accumulation of dirt and other contaminants on their active area, known as soiling. The rate of soiling accumulation can be very site-specific. Areas with higher soiling may require more frequent module cleaning, corresponding to an increase in operation and maintenance costs. Soiling tends to accumulate at a higher rate in dry or dusty regions. Rainfall is also important, since rain can often clean the systems quite effectively. Any site-specific features like proximity to dirt roads or sources of airborne contaminants should also be considered.
- Based on the site hot water usage profile and demand, it may be recommended to utilize a heat dump to dissipate the excess unused heat during times of low heat demand. This is to ensure that the surplus heat does not impact the system performance by causing the array to automatically de-track as a protection mechanism.

General cost drivers:

- Raw material costs, such as the costs of aluminum and steel.
- The availability of high-efficiency silicon photovoltaic cells reduces the $/W or $/kWh cost of Cogenra's low-concentration cogeneration system. Since Cogenra's SunDeck system requires only 1/8th the silicon cell area of traditional PV modules, Cogenra can effectively leverage higher-efficiency cells to greatly reduce overall cost. As high-efficiency silicon PV cell technologies continue to improve, this will drive down the cost of Cogenra's system more rapidly than modules that require much more cell area.

7.3 COST ANALYSIS AND COMPARISON

Life-cycle cost analysis for implementing the demonstrated technology in its current version (roof-top) and comparison to Cogenra's recently released ground-mount version was performed. For future deployments of the technology, Cogenra's ground-mount version of the system is

what will likely be deployed as this version and associated improvements have enabled significant cost reduction of the technology.

A cogeneration system similar to the type installed at Port Hueneme and PRFTA but with updated receivers utilizing the latest available high-efficiency cells has been considered. The table below outlines the system capacity utilized in this analysis. The energy production values are for locations similar to Port Hueneme and PRFTA with respect to solar resources.

Table 12: System Size and Performance for Cost Analysis

Combined ESTCP Installation	System Size (updated with current technology)	Annual Energy Displaced
Electric	69 kW (e)	113,220 kWh
Thermal	1555 kW(th)	21,560 therms

The life-cycle cost analysis was computed for the demonstrated technology based on the system and operational assumptions listed below:

Table 13: Assumptions for Cost Analysis

System Inputs	
Cogenra Modules	144
Cogenra Equivalent Rating (W-dc)	480
Cogenra STC Rating (Wp-dc)	600
Installed Capacity (kW-dc)	69
Installed Price ($)	915,605
CPV- Elec Prod / Mod (KWh)	786
Energy Yield (AC) KWh / KWeq	1,638
PVT- Elec Prod / Mod (KWh)	786
PVT-Thermal Prod / Mod (KWh)	3,510
PVT-Heat Utilization (annual avg)	100%
Boiler Efficiency	80%
PV Performance Degradation (annual)	-0.5%

Operational Inputs	
Monthly Rent	$0
PV O&M ($/Module)	$10.0
Thermal O&M ($/Module)	$2.5
O&M Escal. Rate	3.0%
Insurance Rate	0.0%
Insurance Escalation	0.0%
Inverter 10th Yr Repair ($/W)	0.10

Financial Inputs	
Federal Tax Rate	35%
State Tax Rate	5.8%
Bonus Depreciation	NO
Fed Depreciation	MACRS
State Depreciation	MACRS
Cost of Equity(%)	6.0%
% of Debt	0.0%
Interest on Debt(%)	5.0%
Duration of Debt (Yrs)	12.0
WACC	6.0%

Rate Inputs	
Electricity Price ($/kWh)	$0.1350
Electric Escalation Rate (annual)	4.0%
Thermal Price ($/Therm	$0.8400
Thermal Escalation Rate (annual)	3.0%
CSI Electric PBI ($/kWh)	$0.000
CSI Thermal PBI ($/kWh)	$0.303

The cash flow economics offered by the demonstrated technology with 25 year lifetime was developed and results are shown in the tables below. The payback for the project with the updated receiver technology is expected to be little over 5 years. This payback metric and the return on investment depends significantly on the energy usage and demand profile of the barracks and building sites. During the course of this study it was found that the actual demand fluctuated severely depending on occupancy of the barracks. This lack of demand impacts the performance of the array since there is when there is no off-take for the thermal energy generated by the solar array, the solar thermal storage tank reaches it upper temperature limit and triggers the solar array to de-track to mitigate over-heating. During de-tracking the array produces neither electricity nor solar hot water and this will in-turn impact the economics of the project.

Table 14: Financial analysis for Cogenra's rooftop solar cogeneration system

Effective Purchase Price[1]	Typical Annual Revenue[2]	Payback Period[3]	Return on Net Investment	Unlevered IRR[4]
$238,399	**$33,393**	**5.1 Years**	**1.94x**	**15.4%**

NOTES
1) Net price after 30% ITC tax credit, Year-1 MACRS tax impact, solar hot water rebates
2) No $-value attributed to Carbon offset
3) After tax payback period
4) Unlevered, after-tax IRR
5) Contingent upon final site inspection and permitting
6) Assumes 40.8% total tax(Federal + State)
7) Assumes electric rate at $0.135/kWh, 4% escalation
8) Assumes natureal gas rate at $0.84/Therm, 3% escalation
9) Assuming current consumption patterns.

System Costs & Rebates	$	Comments
Installed Cost	915,605	Includes standard warranty
ITC Tax Credit 30%	(274,682)	Federal Incentive
SHW Rebate	(382,259)	California Solar Initiative- Thermal Incentive
Net Tax Impact	(20,265)	MACRS
Effective Purchase Price	**238,399**	

1st Year Revenue Streams	$/Year	Comments
Electric Incentive	0	
Fuel	18,109	At $0.84/Therm
Electric	15,285	At $0.135/kWh
Carbon / RECs	0	No $-value attributed to carbon offsets
O&M	(1,800)	Maintenence
Net Revenues / Year	**$31,593**	
Payback Period (Years)	**5.1**	
Project Equity IRR (unlevered)	**15.4%**	4% annual Electricity escalation & 3% Natural gas escalation

The cumulative cash flow due to the displaced energy savings for the 25 year operational life time of the system is shown in chart below:

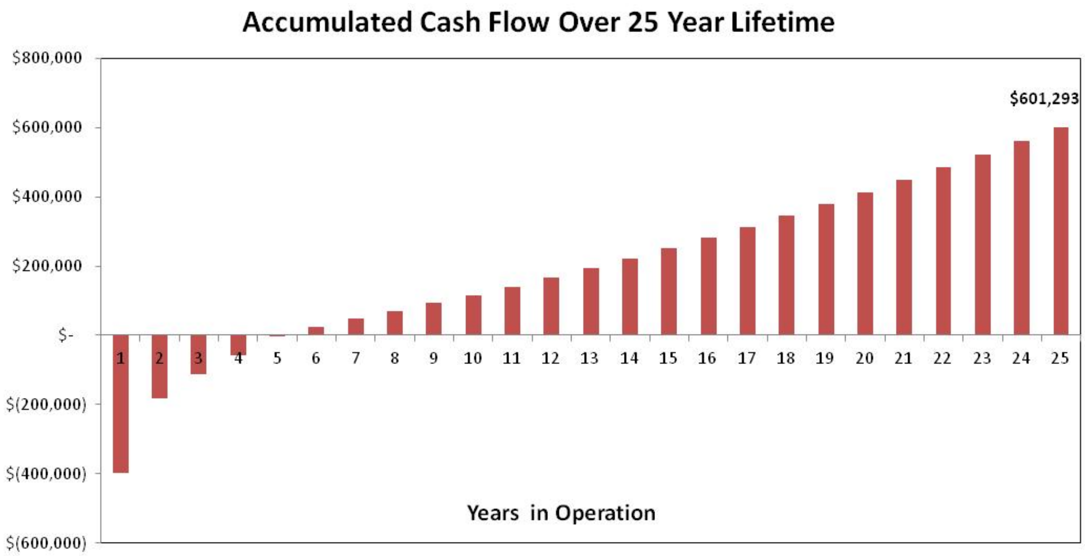


Figure 30: SunDeck Cash Flow

The sensitivity of the system payback for several parameters was evaluated and shown in Table 12:

1. Energy rates (electric and thermal value of energy metric)
2. Solar resource (Direct Normal Irradiation metric)
3. Hot water demand (utilization of heat metric)

Table 15: Sensitivity of system payback to various site-specific parameters. The sensitivity analyses were computed for DNI = 1700 kWh/m2 with 100% heat utilization for part-1 and with $0.135/kWh and $0.84/Therm for Part-2 of the table

Payback in years		Annual Average Electric Rate, $/kWh		
		0.100	**0.135**	**0.150**
Gas Rate $/Therm	**0.60**	6.7	5.8	5.5
	0.84	5.6	5.1	4.9
	1.00	5.1	4.8	4.8

Payback in years		% Heat utilization (demand variation)			
		100%	**80%**	**60%**	**50%**
DNI Variation kWh/m2-yr	**1600**	5.9	8.7	12.3	14.2
	1700	5.1	7.7	11.3	13.1
	1900	4.4	6.0	9.3	11.3
	2100	3.8	4.9	7.7	9.7
	2300	3.4	4.4	6.4	8.2
	2500	3.2	3.9	5.4	7.1

Cogenra has since the installation of this project developed a financing relationship with a financial partner. This enables Cogenra’s technology to be implemented at DoD sites without any up-front cost while utilizing the economic benefits of the tax credits (ITC) currently in place from the U.S federal government. The benefits of a PPA structure are elaborated in the figure below:

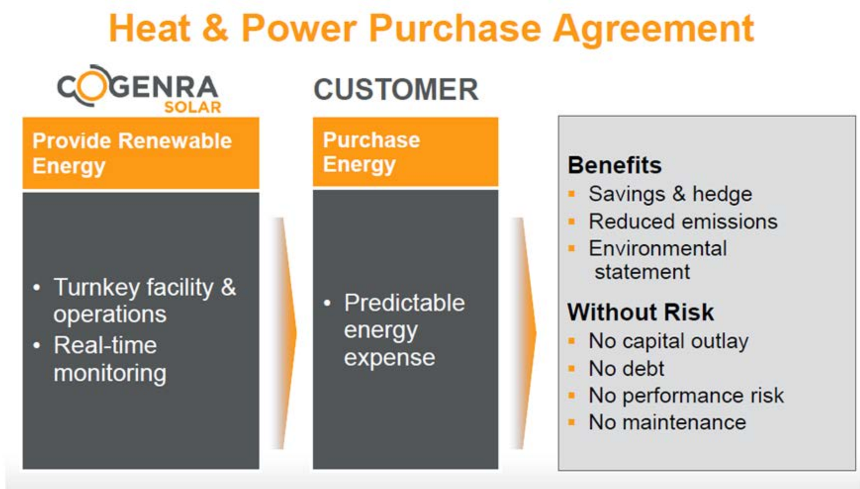


Figure 31: Advantages of HPPA or PPA

If this demonstration project were contracted as a PPA financed project, then the site would be eligible for the following discounted energy rates and savings:

1,624 KW (e+th)			
	Proposed PPA Rates	Current Energy Rates	Discount
Electric	$0.125 / KWh	$0.135 / KWh	7.4%
Thermal	$0.50 / therm	$0.84 / therm	40.5%
PPA Contract Term: 25 Years			

NOTES
1) Annual PPA escalation rates of 3% electric and 2% gas

Lifetime Energy Savings, HPPA												
Year			**Yr1**	**Yr2**	**Yr3**	**Yr4**	**Yr5**	**...**	**Yr10**	**...**	**Yr25**
Status Quo -->	Utility Power Prices	$/kWh	$0.135	$0.140	$0.146	$0.152	$0.158	...	$0.192	...	$0.346
With Cogenra-->	Solar PPA Pricing	$/kWh	$0.125	$0.129	$0.133	$0.137	$0.141	...	$0.163	...	$0.254
Discount			7%	8%	9%	10%	11%	...	15%	...	27%
Status Quo -->	Utility Gas Prices	$/Therm	0.84	0.87	0.89	0.92	0.95	...	1.10	...	1.71
With Cogenra-->	Solar PPA Pricing	$/kWh	0.50	0.51	0.52	0.53	0.54	...	0.60	...	0.80
Discount			40%	41%	42%	42%	43%	...	45%	...	53%
Status Quo -->	Annual Utility Payment	$	$33,393	$34,468	$35,578	$36,724	$37,907	...	$44,423	...	$71,549
With Cogenra-->	Annual Solar Payment	$	$24,931	$25,499	$26,079	$26,673	$27,280	...	$30,533	...	$42,845
		Annual Savings	$8,462	$8,970	$9,499	$10,052	$10,627	...	$13,890	...	$28,704
Cumulative Savings			$8,462	$17,432	$26,931	$36,983	$47,610	...	$110,267	...	$426,249

NOTES
1) Annual PPA escalation rates of 3% electric and 2% gas

Life-cycle Cost Analysis for Future System:

We performed life-cycle cost analysis for Cogenra's recently released T14 system which is a 14x concentrating system for ground-mount applications. The aperture area of the concentrator on this T14 system is roughly twice the aperture area of the SunDeck modules implemented in the ESTCP demonstration projects.

The figures below show a schematic of the T14 system and the implementation of it at the TEP-SolarZone site in Tucson, Arizona.

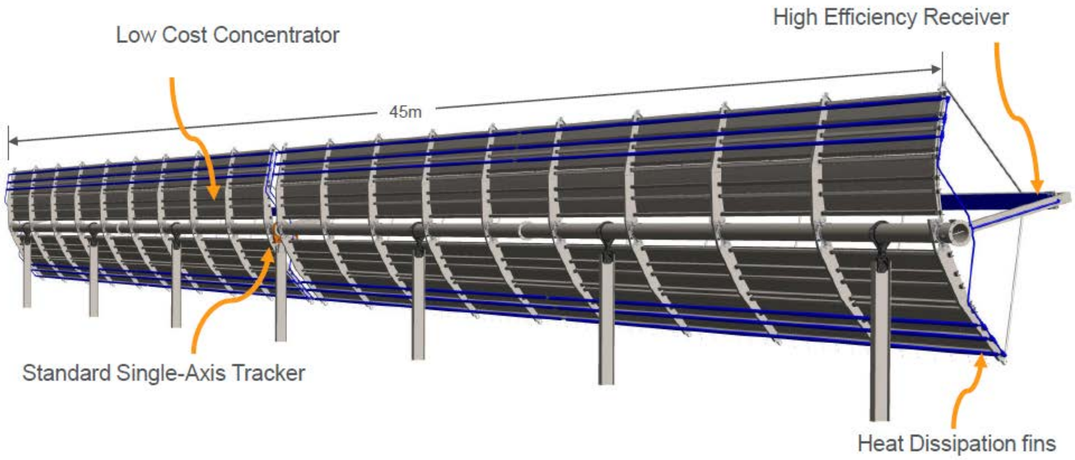


Figure 32: Schematic of the Cogenra T14 system

Figure 33: Cogenra T14 systems deployed in a 1.1MW array in Tucson, AZ

The Cogenra T14 systems allow the flexibility to be configured as pure-PV systems (with the thermal energy being dissipated effectively with finned-tubes within system) or as PV-Thermal systems where is the heat is captured and delivered for use. For example, this flexibility allows for a hybrid array where 1MW of PV T14 systems can be configured to have 30% of them as

PV-Thermal cogeneration depending on the heat demand and usage profile of the customer. If the customer has no heat demand the entire array can be configured as pure-PV.

The life-cycle analysis shown below incorporated 60 T14 systems to form a 1,080kW-DC PV array with 25 of the T14 systems configured as PV-Thermal and the rest configured as PV-only. This rated capacities and production of this hybrid array are shown in the table below:

Future DOD Installation	Size	Annual Energy Displaced
Electric	1,080 kW (e)	1,686,133 kWh
Thermal	1,620 kW(th)	70,433 Therms

The life-cycle cost analysis was computed for T14 technology based on the system and operational assumptions listed below:

System Inputs	
Cogenra Modules	1,080
Cogenra Equivalent Rating (W-dc)	1,000
Cogenra STC Rating (Wp-dc)	1,100
Installed Capacity (kW-dc)	1,080
Installed Price ($)	3,000,000
CPV- Elec Prod / Mod (KWh)	1,610
Energy Yield (AC) KWh / KWeq	1,610
PVT- Elec Prod / Mod (KWh)	1,493
PVT-Thermal Prod / Mod (KWh)	4,104
PVT-Heat Utilization (annual avg)	95%
Boiler Efficiency	85%
PV Performance Degradation (annual)	-0.5%

Operational Inputs	
Monthly Rent	$0
PV O&M ($/Module)	$20.0
Thermal O&M ($/Module)	$5.0
O&M Escal. Rate	3.0%
Insurance Rate	0.0%
Insurance Escalation	0.0%
Inverter 10th Yr Repair ($/W)	0.10

Financial Inputs	
Federal Tax Rate	35%
State Tax Rate	5.8%
Bonus Depreciation	NO
Fed Depreciation	MACRS
State Depreciation	MACRS
Cost of Equity(%)	6.0%
% of Debt	0.0%
Interest on Debt(%)	5.0%
Duration of Debt (Yrs)	18.0
WACC	6.0%

Rate Inputs	
Electricity Price ($/kWh)	$0.1350
Electric Escalation Rate (annual)	4.0%
Thermal Price ($/Therm	$0.8400
Thermal Escalation Rate (annual)	3.0%
CSI Electric PBI ($/kWh)	$0.000
CSI Thermal PBI ($/kWh)	$0.303

The cash flow economics offered by the T14 technology with 25 year lifetime was developed and results are shown in the tables below. The payback for the project with the updated receiver technology is expected to be less than 5 years.

Effective Purchase Price[1]	Typical Annual Revenue[2]	Payback Period[3]	Return on Net Investment	Unlevered IRR[4]
$1,445,140	**$286,792**	**5 Years**	**3.46x**	**21.6%**

NOTES
1) Net price after 30% ITC tax credit, Year-1 MACRS tax impact, solar hot water rebates
2) No $-value attributed to Carbon offset
3) After tax payback period
4) Unlevered, after-tax IRR
5) Contingent upon final site inspection and permitting
6) Assumes 40.8% total tax(Federal + State)
7) Assumes electric rate at $0.135/kWh, 4% escalation
8) Assumes natureal gas rate at $0.84/Therm, 3% escalation

System Costs & Rebates	$	Comments
Installed Cost	3,000,000	Includes standard warranty
ITC Tax Credit 30%	(900,000)	Federal Incentive
SHW Rebate	(500,000)	California Solar Initiative- Thermal Incentive
Net Tax Impact	(154,860)	MACRS
Effective Purchase Price	**1,445,140**	

1st Year Revenue Streams	$/Year	Comments
Electric Incentive	0	
Fuel	59,164	At $0.84/Therm
Electric	227,628	At $0.135/kWh
Carbon / RECs	0	No $-value attributed to carbon offsets
O&M	(23,850)	Maintenence
Net Revenues / Year	**$262,942**	
Payback Period (Years)	**4.8**	
Project Equity IRR (unlevered)	**21.6%**	4% annual Electricity escalation & 3% Natural gas escalation

The cumulative cash flow due to the displaced energy savings for the 25 year operational life time of the system is shown in chart below:

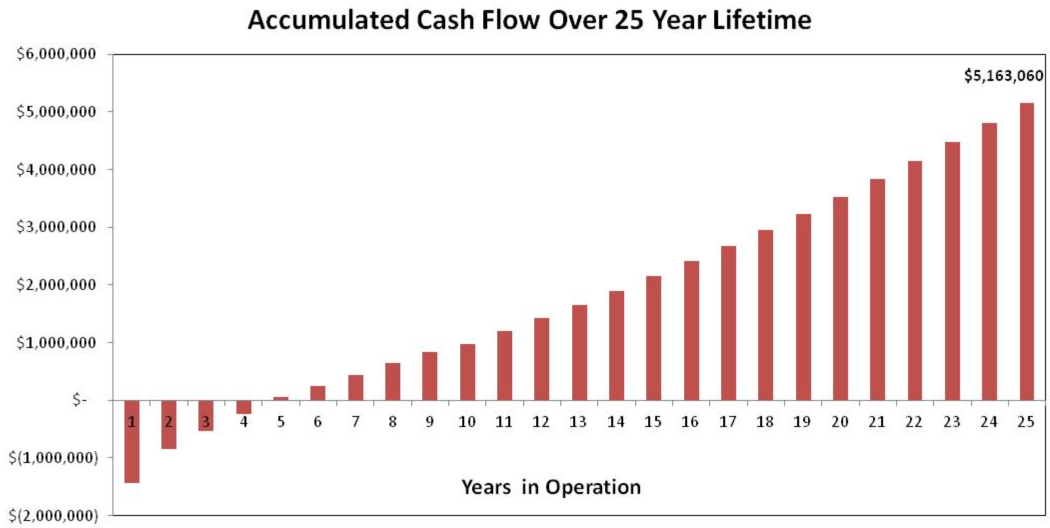


Figure 34: T14 Cash Flow

If the project were contracted as a PPA financed project, then the site would be eligible for the following discounted energy rates and savings:

2,700 KW (e+th)			
	Proposed PPA Rates	Current Energy Rates	Discount
Electric	$0.120 / KWh	$0.135 / KWh	11.1%
Thermal	$0.50 / therm	$0.84 / therm	40.5%
PPA Contract Term: 25 Years			

NOTES
1) Annual PPA escalation rates of 3% electric and 2% gas

Lifetime Energy Savings, HPPA												
Year			Yr1	Yr2	Yr3	Yr4	Yr5	...	Yr10	...	Yr25
Status Quo -->	Utility Power Prices	$/kWh	$0.135	$0.140	$0.146	$0.152	$0.158	...	$0.192	...	$0.346
With Cogenra-->	Solar PPA Pricing	$/kWh	$0.120	$0.124	$0.127	$0.131	$0.135	...	$0.157	...	$0.244
Discount			11%	12%	13%	14%	14%	...	19%	...	30%
Status Quo -->	Utility Gas Prices	$/Therm	0.84	0.87	0.89	0.92	0.95	...	1.10	...	1.71
With Cogenra-->	Solar PPA Pricing	$/kWh	0.50	0.51	0.52	0.53	0.54	...	0.60	...	0.80
Discount			40%	41%	42%	42%	43%	...	45%	...	53%
Status Quo -->	Annual Utility Payment	$	$286,792	$296,488	$306,514	$316,879	$327,596	...	$386,890	...	$637,613
With Cogenra-->	Annual Solar Payment	$	$237,553	$243,285	$249,156	$255,170	$261,330	...	$294,444	...	$421,331
		Annual Savings	$49,239	$53,203	$57,357	$61,709	$66,266	...	$92,446	...	$216,282
Cumulative Savings			$49,239	$102,443	$159,800	$221,509	$287,775	...	$695,275	...	$2,973,671

8 IMPLEMENTATION ISSUES AND DESIGN TOOLS

One challenge encountered during this demonstration project was low or inconsistent hot water demand at times. We have identified several solutions for dealing with varying thermal demand, some of which are already in use in Cogenra systems. The various parameters that can be controlled to optimize the proportion of electricity and heat generation are:

i. **Flow control:** Controlling the flow of the heat transfer fluid can allow for higher electricity production by running the PV cells cooler than normal.

ii. **Heat dissipation:** Utilization of heat dissipation systems that can automatically turn on during times of high electrical demand or higher time of use value for electricity. This heat dissipation can be operated at maximum flow so as to enable a significantly lower photovoltaic cell temperature and hence higher electricity production. As mentioned earlier this will also mitigate any energy loss seen from de-tracking of the arrays during low demand times.

iii. **Thermal boost:** The arrays can also be operated in a thermal-only mode for those durations during the day when more hot water production is needed by turning the inverter off so that all the collected solar energy is converted into thermal energy.

Design Tools

Cogenra developed a set of design tools and engineering templates. These tools will significantly reduce engineering time and cost and will enable engineers with littel experience with solar cogeneration technology to design and implement new projects. These tools will also enable DoD installations to utilize a wider array of contractors to design and install solar cogeneration systems.

The following is a list of tools which enables a developer or installer to size the solar cogeneration system based on the roof layout and to do the full design and installation. The documents need to be followed in order. All documents are available for Cogenra partners after signing an NDA with Cogenra.

1. Cogenra SunPack Webinar – Overview of Product, Design, Assembly, Customer Support Resources (Hydronics Calculator, BOS Calculator, Project Plan)

2. 2.0 Configuration Guide – Determining orientation of array, proper configuration, layout

3. 2.0 Configuration Selector – Excel program

4. Calculating Design Wind Pressure – Overview for determining wind loading

5. 2.0 Wind Loading Calculator – Excel program

6. Hydronics Flow Calculator – Excel program

7. Inverter Selection Tool – Excel program

8. Electrical Calculator – Excel program

9. SunDeck Installation Guide – Install Manual

10. SunDeck Pre-CX Guide – PreCX checklist

11. SunDeck CX Guide – CX manual

12. Sundeck Maintenance Guide – Maintenance Manual

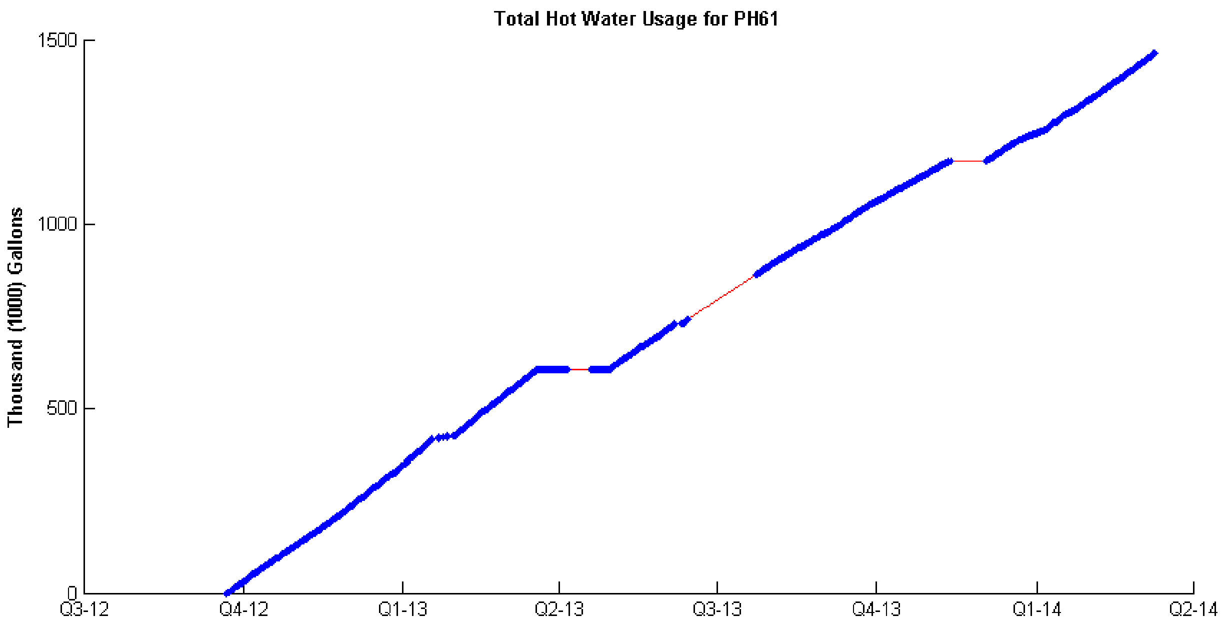
13. SunPack Templates – CAD tools for Sunpack Template, Rotational Clearance, and Data Sheet

14. 2.0 Project Plan – M.O. Project Overview from Lead ID to CX

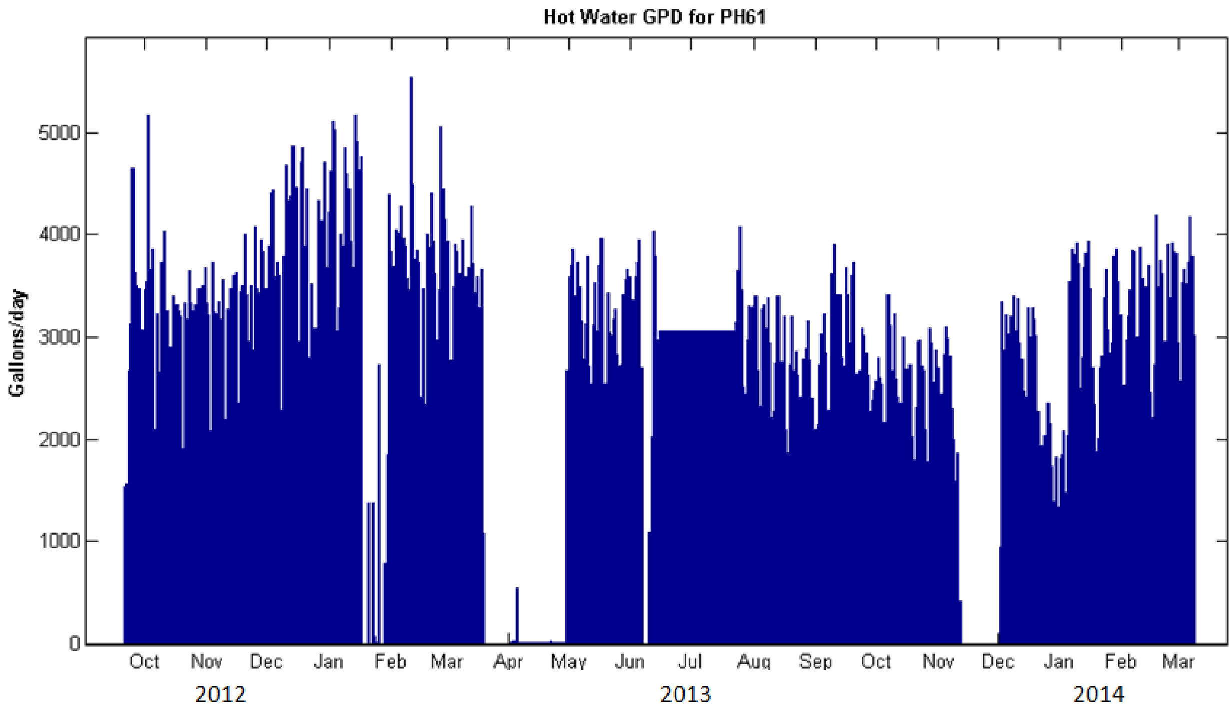
APPENDICES

Appendix A: Baseline Hot Water Usage Metering Data

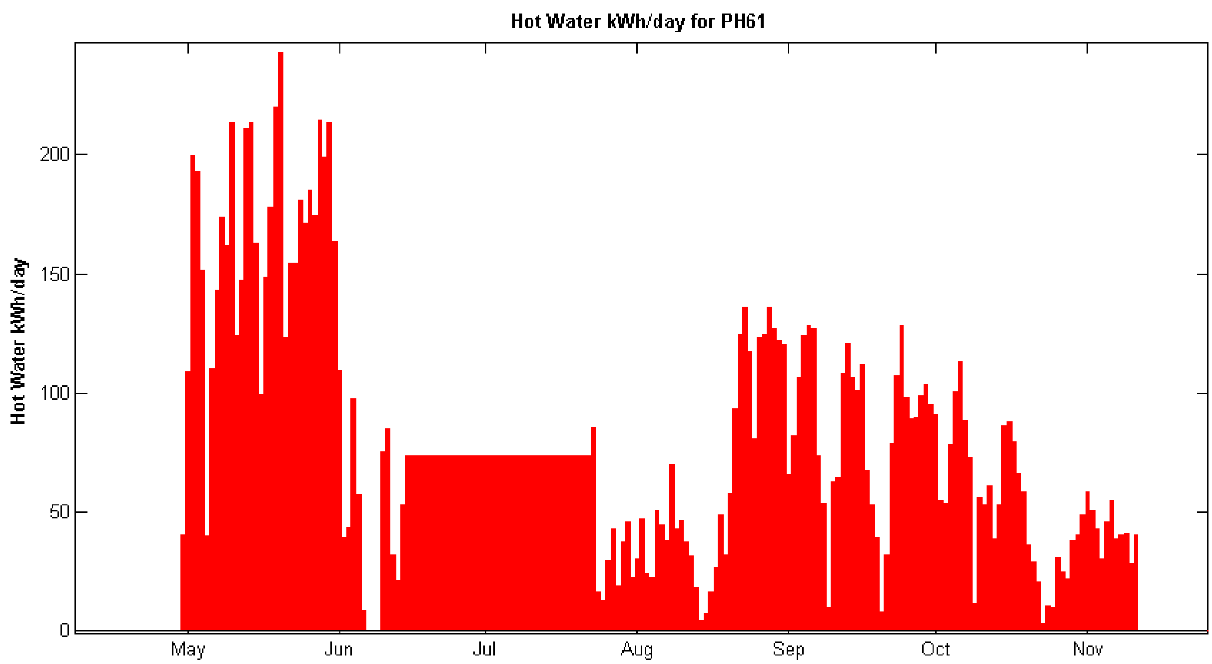
<u>Port Hueneme, Bldg 61</u>



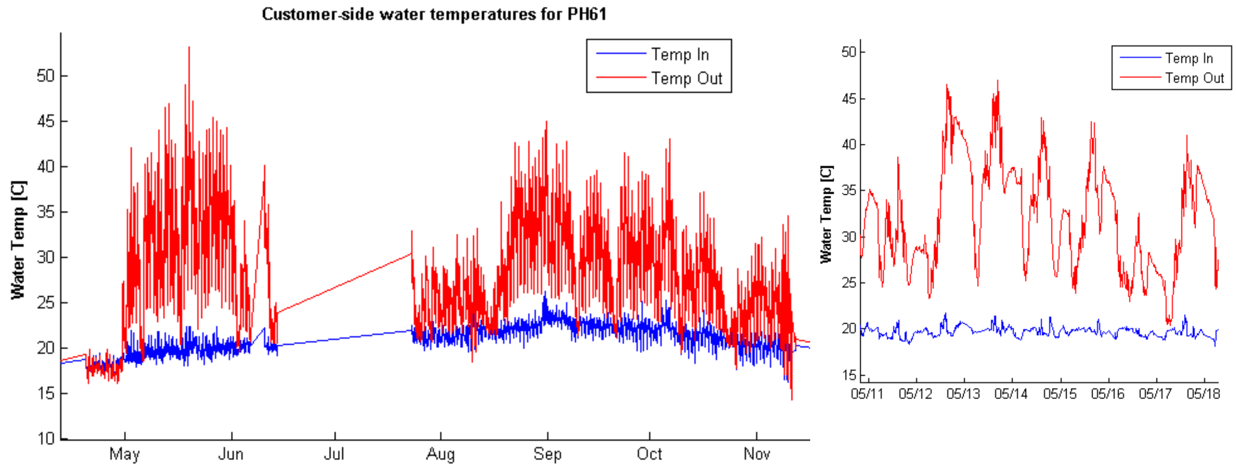
Total (cumulative) customer-side hot water usage. (Red lines show interpolated points.)



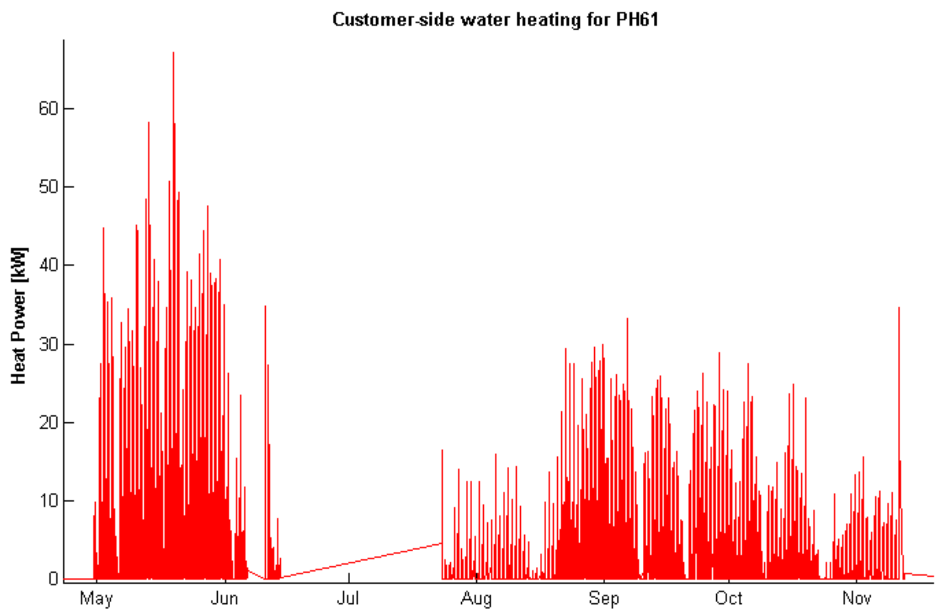
Hot water volume usage per day



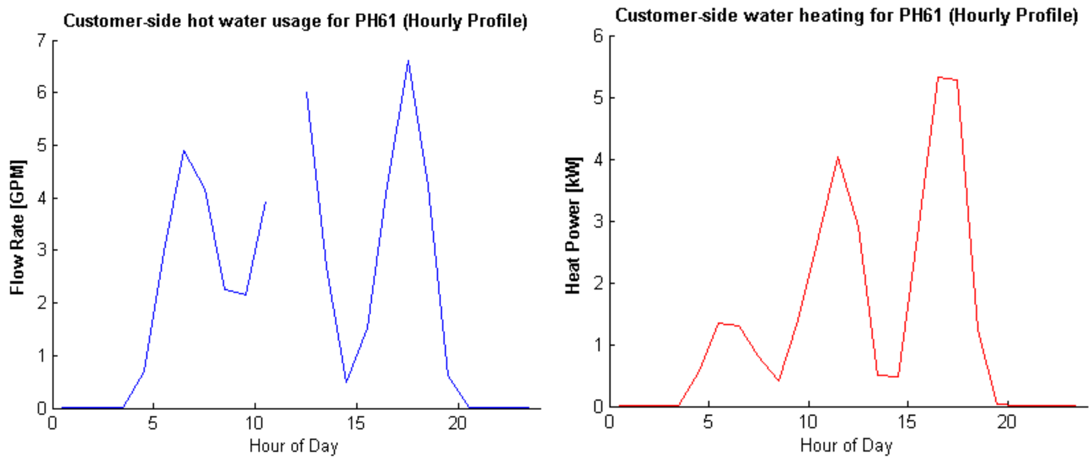
Water heating energy for selected months in 2013.



Hot water temperatures for selected months in 2013, including example of several days.

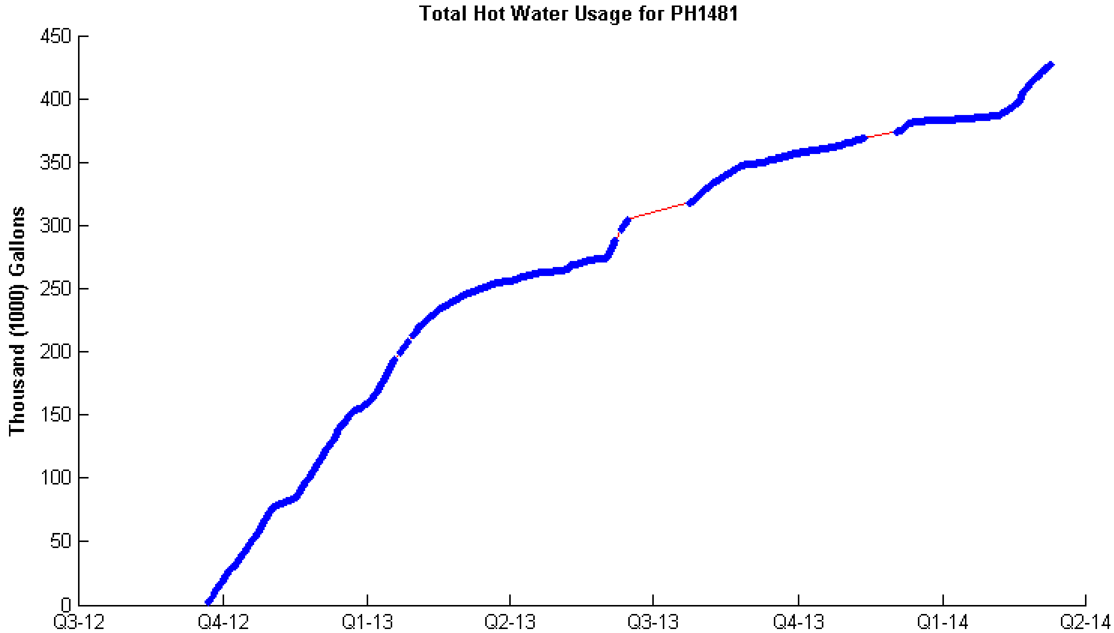


Water heating power for selected months in 2013.

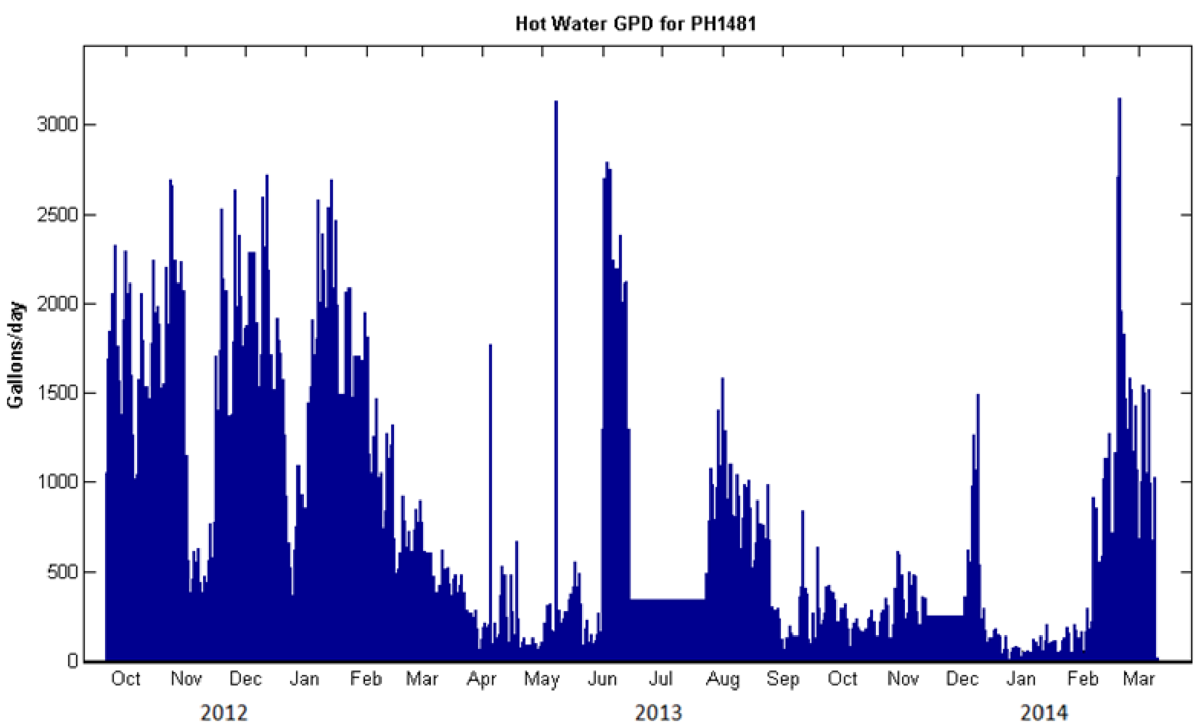


Daily hot water usage profiles. All days with measured hot water usage were combined with an hourly average to determine the typical daily profile.

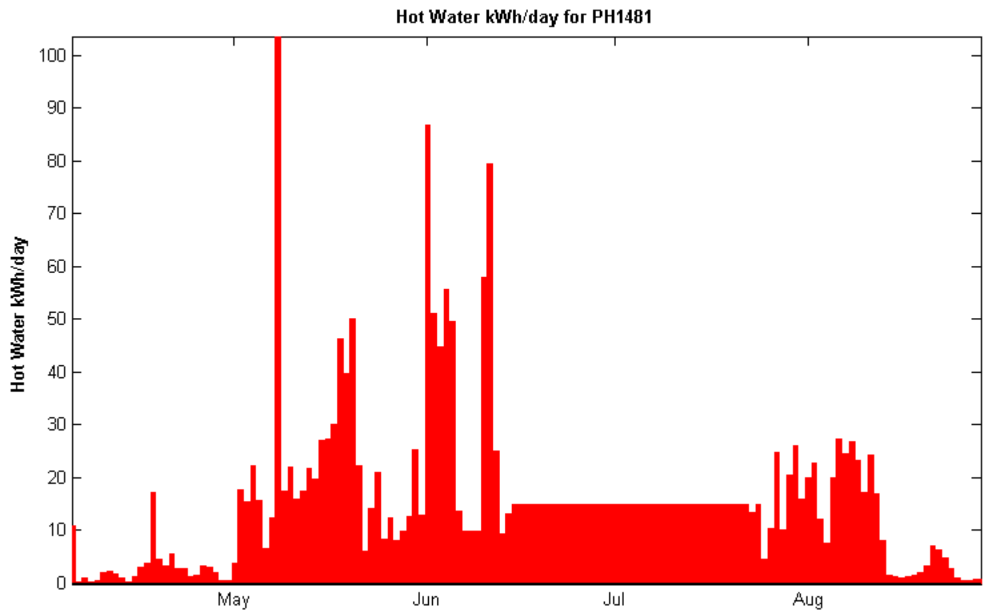
Port Hueneme, Bldg 1481



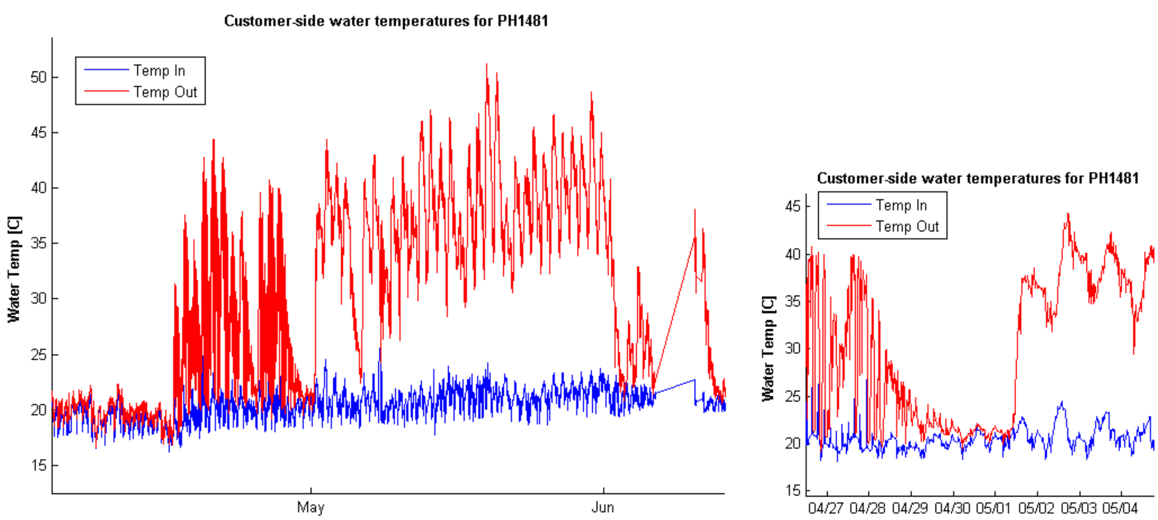
Total (cumulative) customer-side hot water usage. (Red lines show interpolated points.)



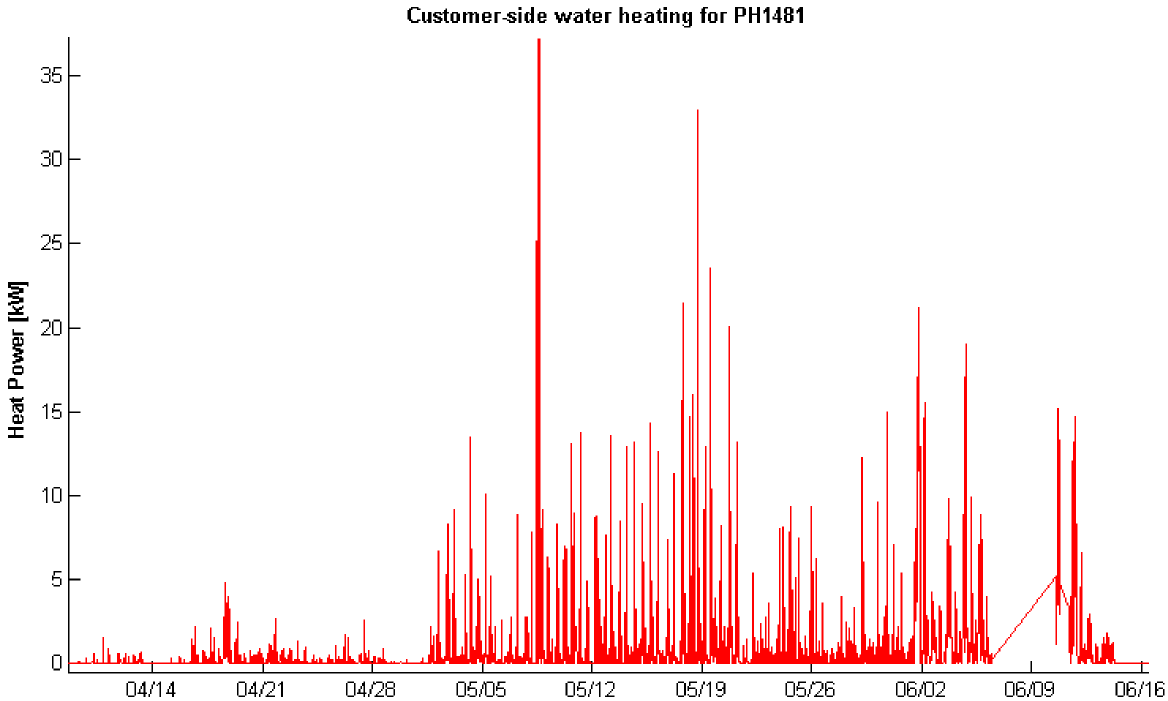
Hot water volume usage per day



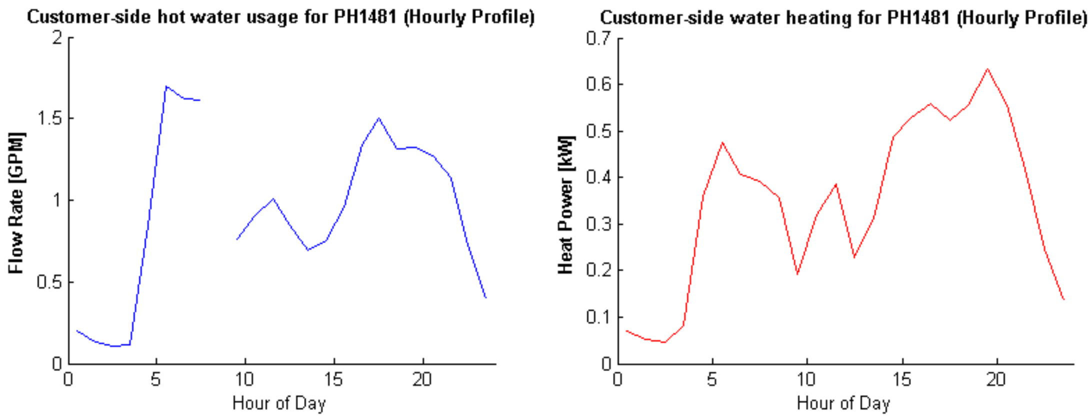
Water heating energy for selected months in 2013.



Hot water temperatures for selected months in 2013, including example daily variation.

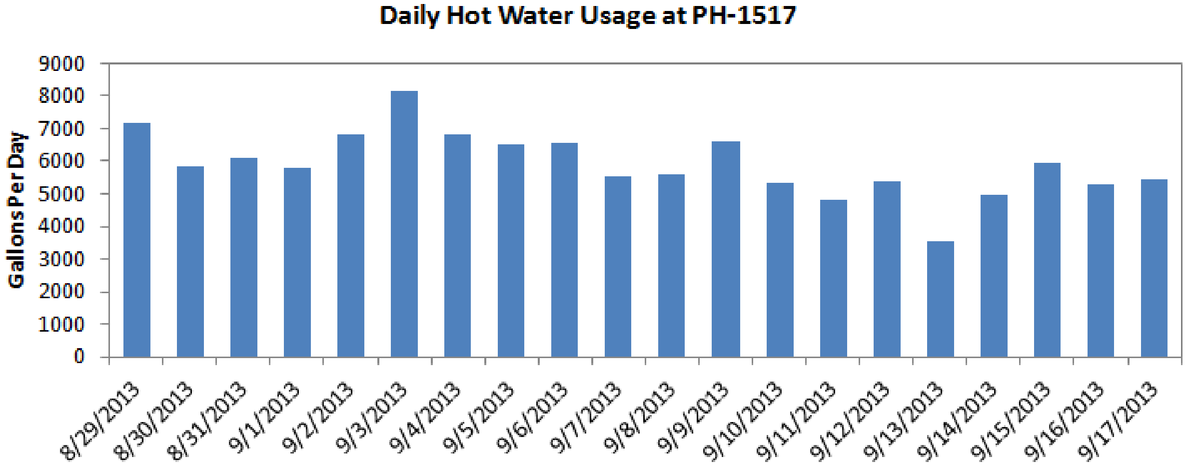


Water heating power for selected months in 2013

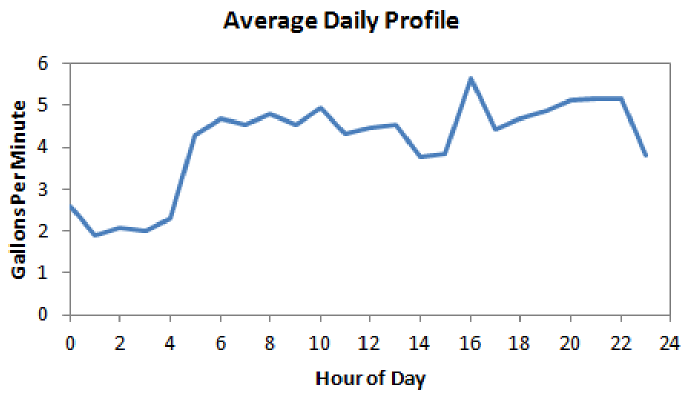


Daily hot water usage profiles. All days with measured hot water usage were combined with an hourly average to determine the typical daily profile.

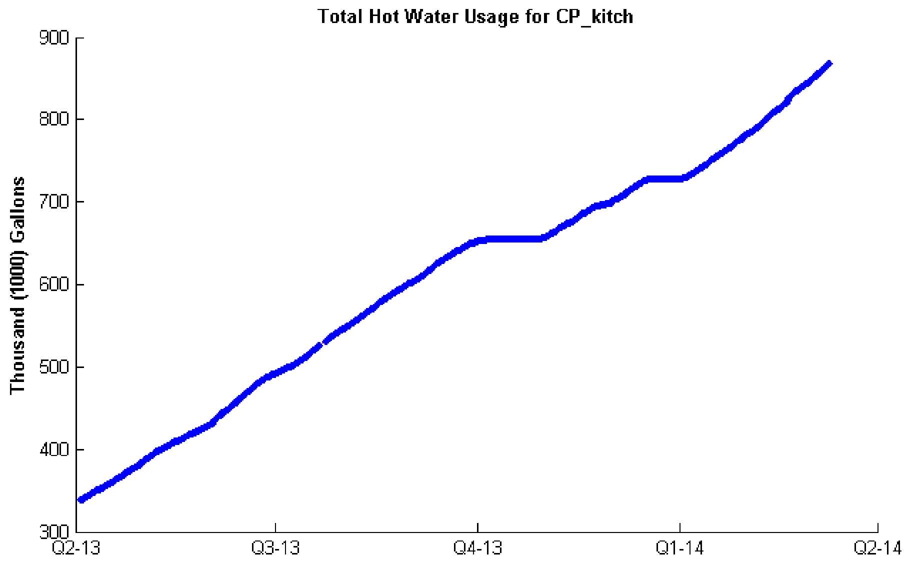
Port Hueneme, Bldg 1517



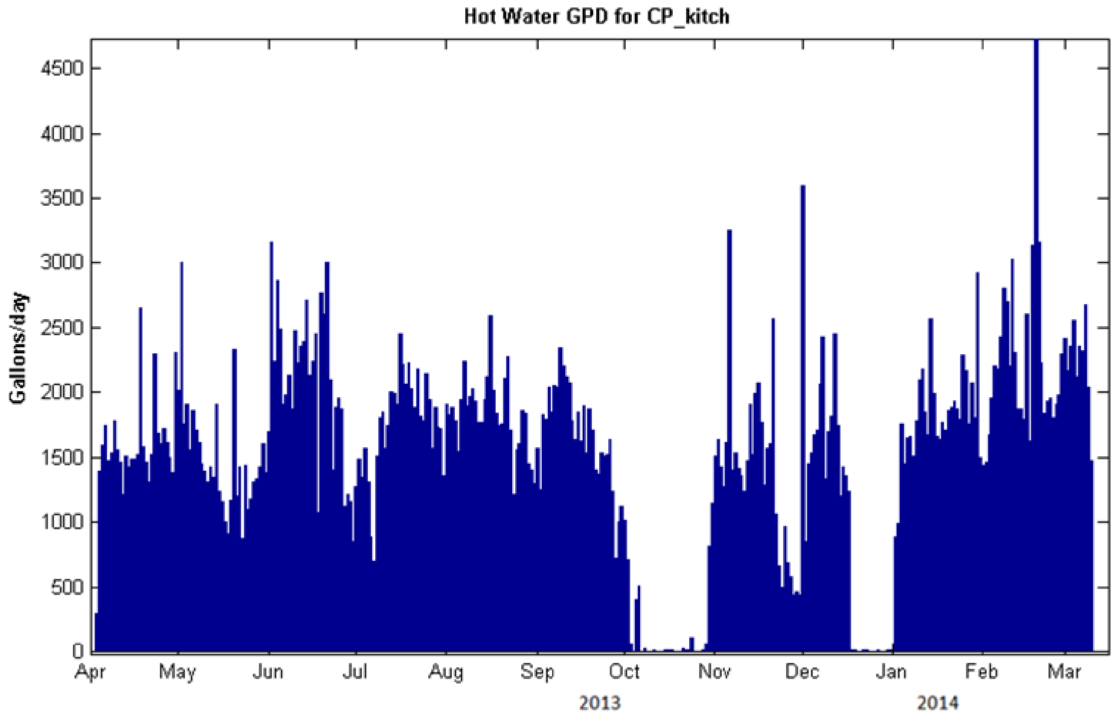
Daily hot water usage at Port Hueneme 1517. The meter that was originally installed did not give reliable results, so the data shown is from an additional meter that was installed for a period of three weeks.



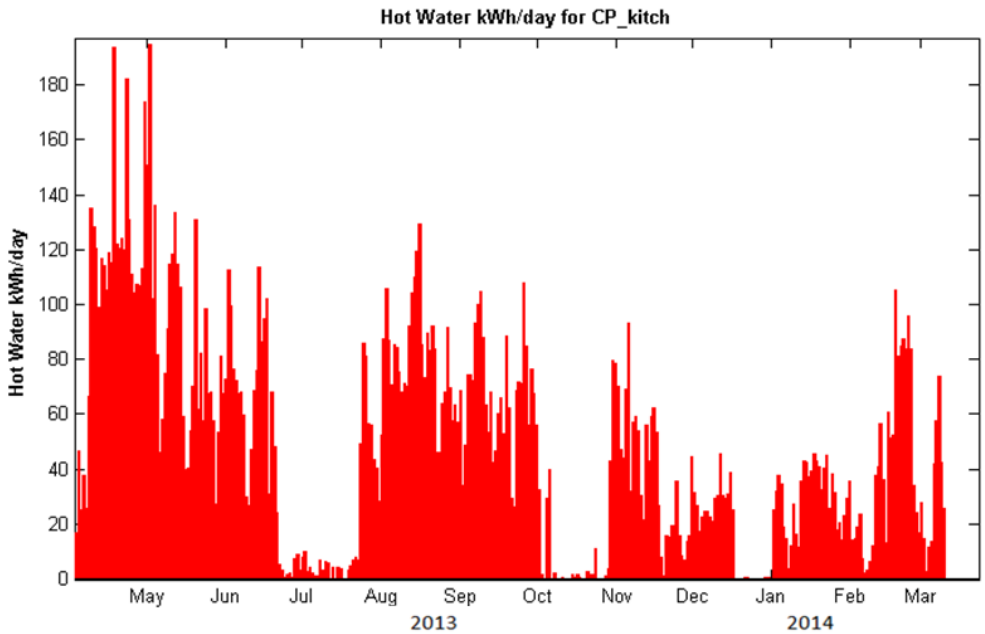
PRFTA, Kitchen



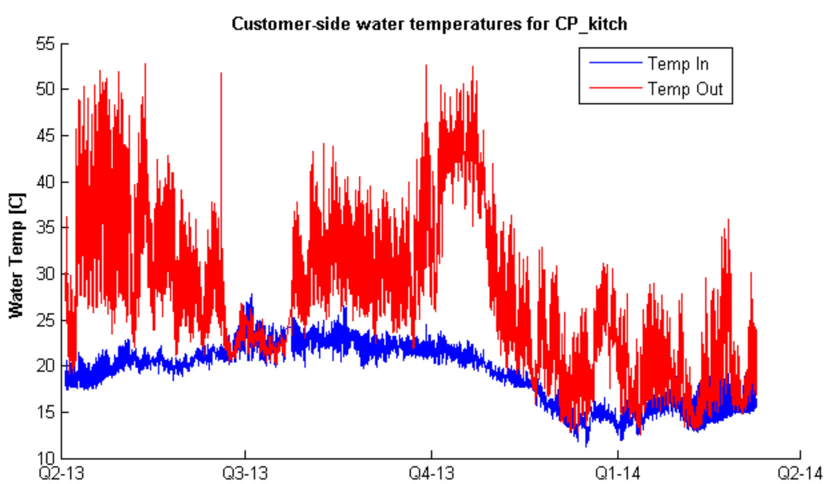
Total (cumulative) customer-side hot water usage. (Red lines show interpolated points.)



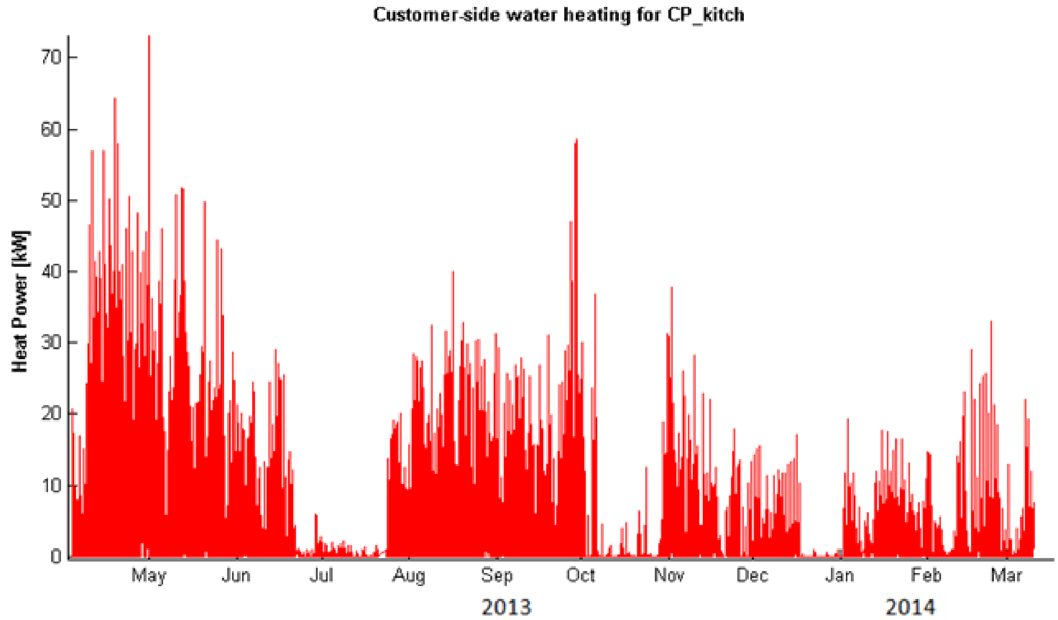
Hot water volume usage per day



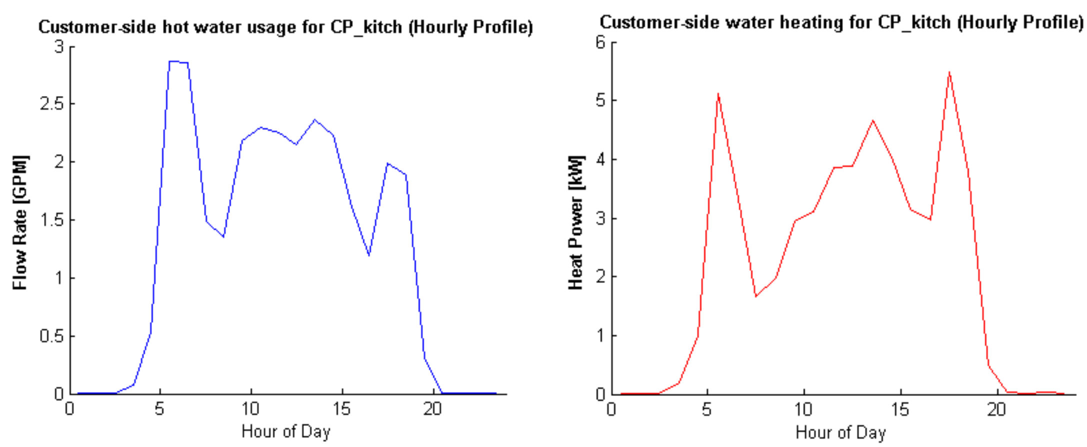
Water heating energy for selected months in 2013 and 2014.



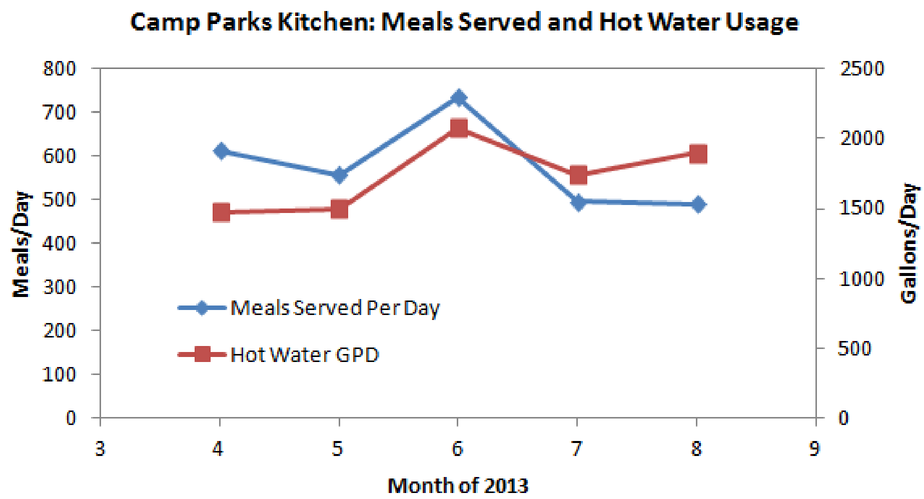
Hot water temperatures for months in 2013 and 2014. Note the clear seasonal variation in cold water supply temperature.



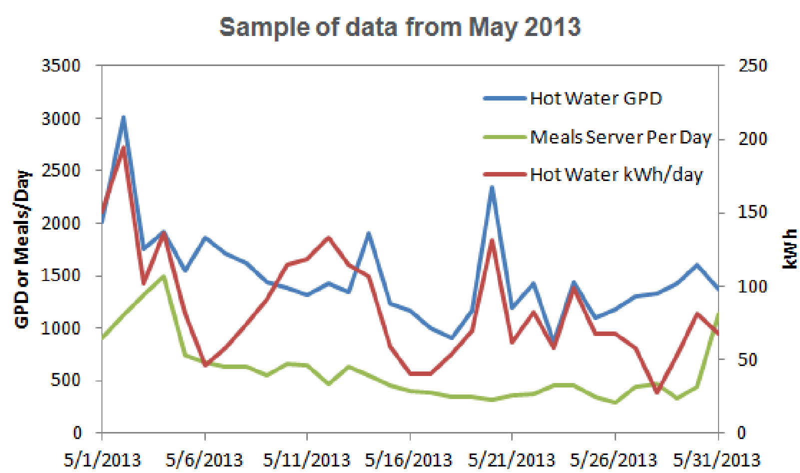
Water heating power for selected months in 2013 and 2014

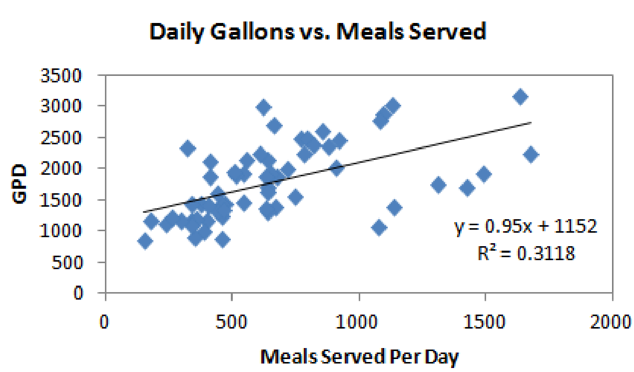


Daily hot water usage profiles. All days with measured hot water usage were combined with an hourly average to determine the typical daily profile.



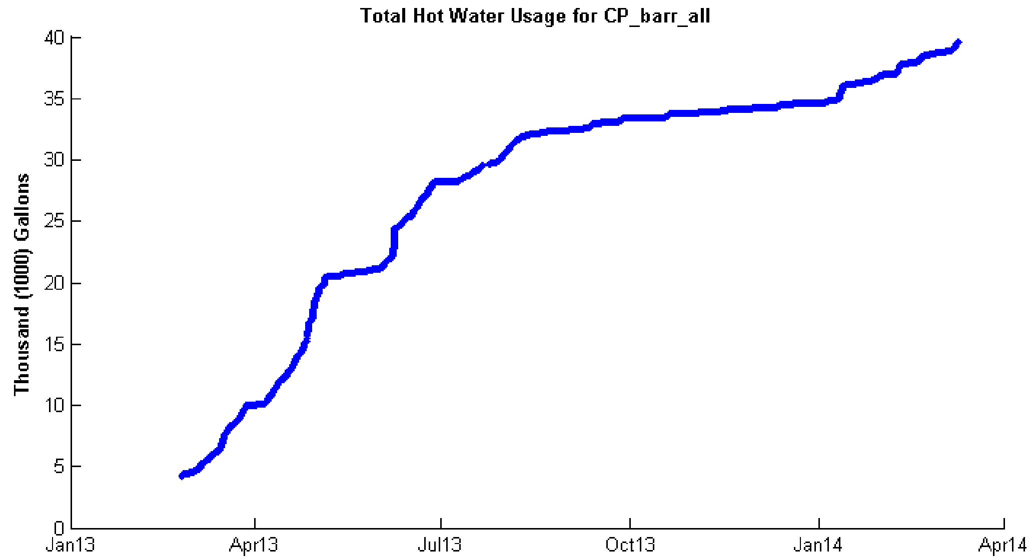
Case study on the correlation between hot water usage and meals served in the kitchen. The data includes breakfast, lunch and dinner meals served by day for several months.



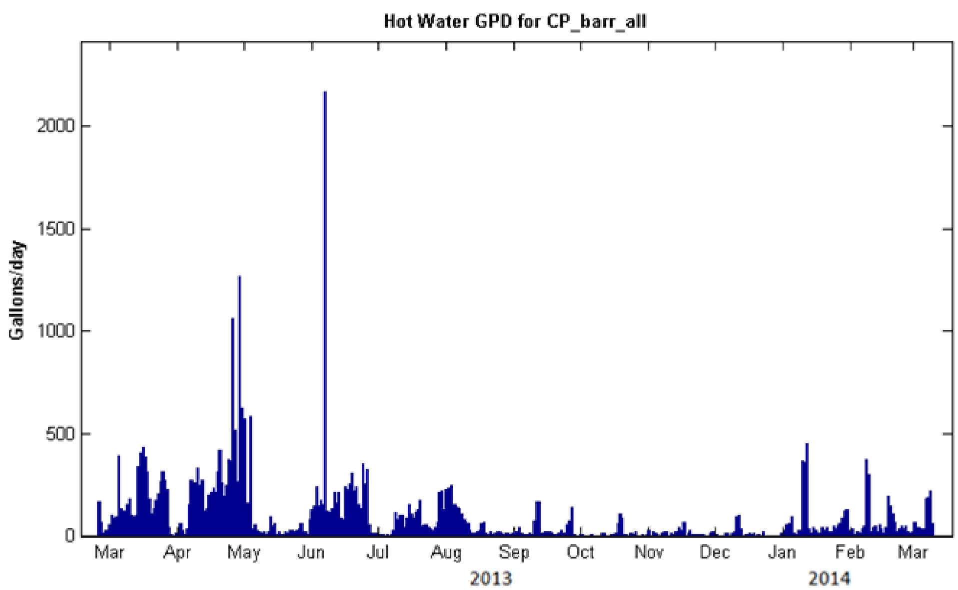


Moderate correlation observed between hot water used and meals served.

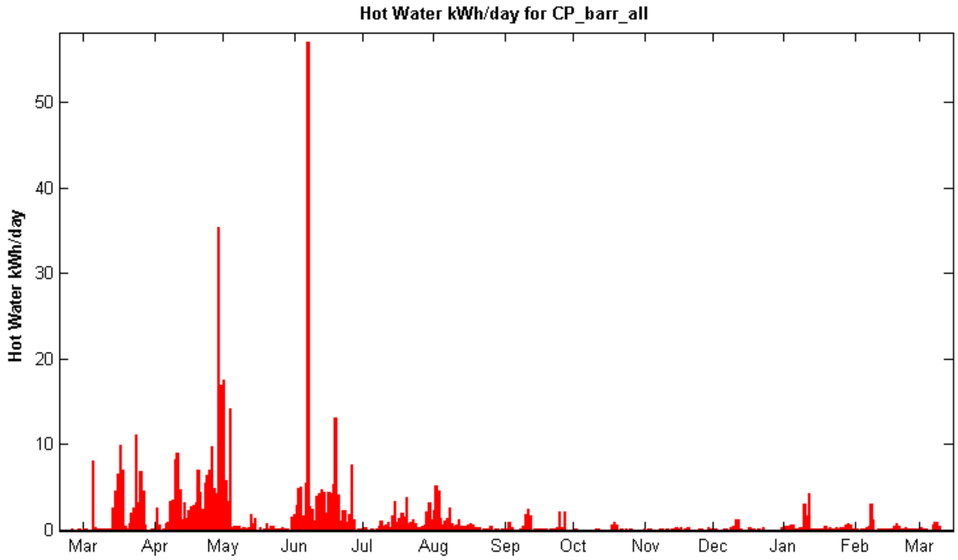
PRFTA, Barracks



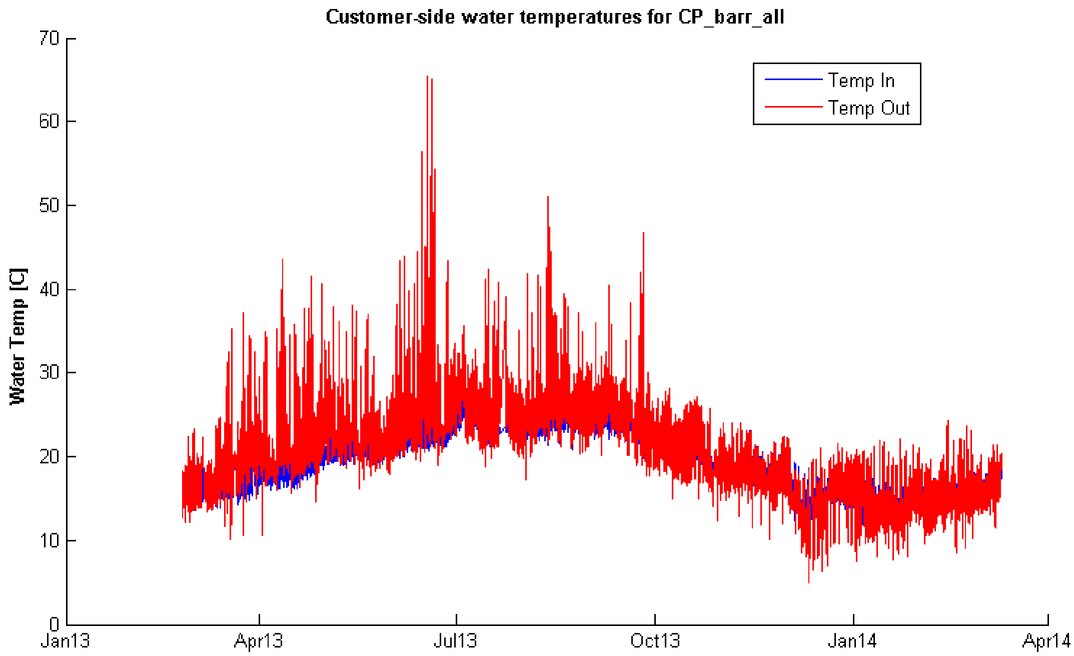
Total (cumulative) customer-side hot water usage. (Red lines show interpolated points.)

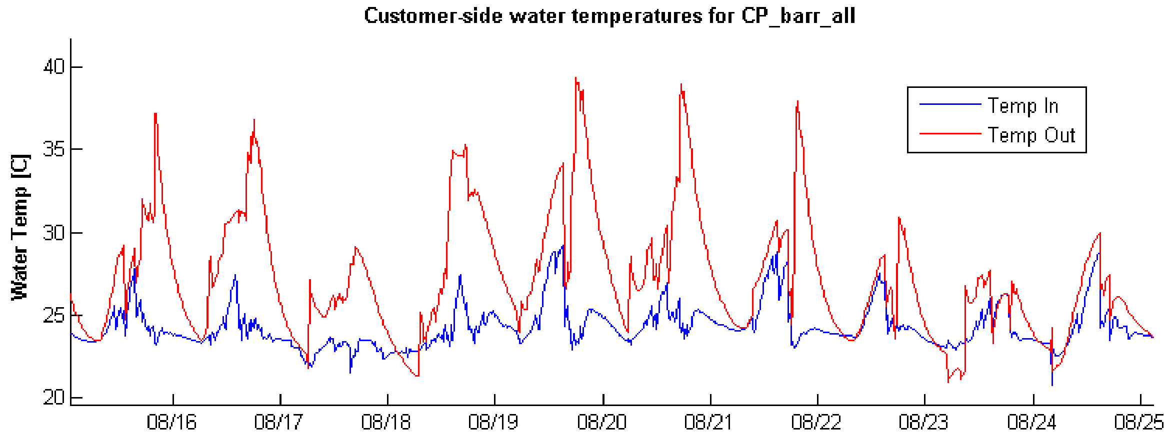


Hot water volume usage per day

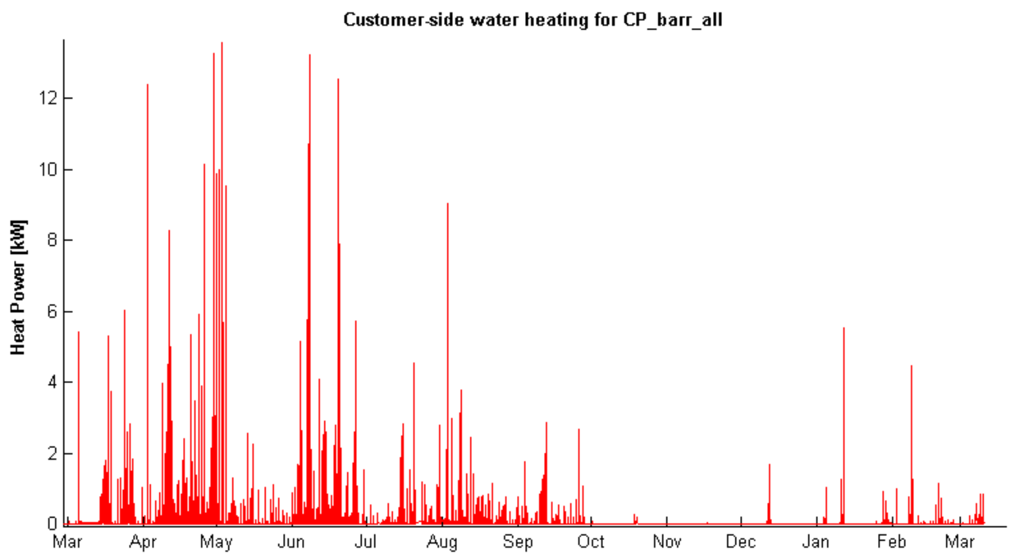


Water heating energy for selected months in 2013 and 2014.

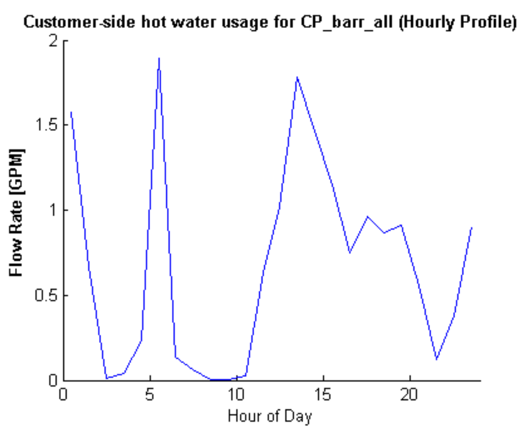


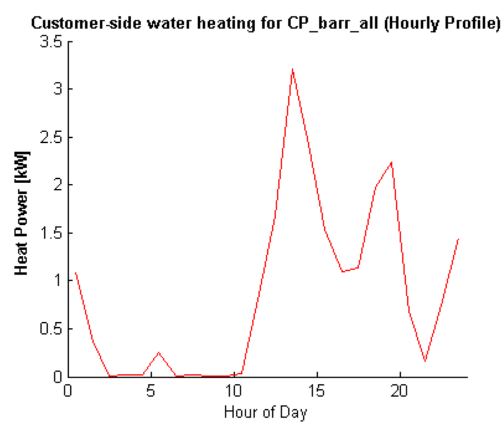


Hot water temperatures for selected months in 2013, including example daily variation.



Water heating power for selected months in 2013 and 2014.





Daily hot water usage profiles. All days with measured hot water usage were combined with an hourly average to determine the typical daily profile.

REFERENCES

Endnotes:

[i] EISA §523 requires that "If lifecycle cost-effective, as compared to other reasonably available technologies, not less than 30% of the hot water demand for each new Federal building or Federal building undergoing a major renovation be met through the installation and use of solar hot water heaters." The Army has restricted the qualifier clause and now requires that "**all** new construction projects with an average daily non-industrial hot water requirement of 50 gallons or more, and located in an area...receiving an annual average of 4 kWh/m2/day or more **will be** designed to provide a minimum of 30% of the facility's hot water demand by solar water heating. Waste heat harvesting, integrated co-generation systems, or a combination thereof may be used in lieu of solar water heating where they achieve equivalent energy savings." (emphasis added) Source: Army Memorandum on Sustainable Design and Development Policy Update (Environmental and Energy Policy) dated October 27, 2010 and signed by Katherine Hammack, Assistant Secretary of the Army (Installations, Energy, Environment).

[ii] The US Army Corps of Engineers has concluded that conventional solar hot water is rarely cost-effective over its life cycle unless implemented in a district wide configuration, and even then generally has a long payback time typically much longer than 20 years. District wide heating is not always possible and by increasing minimum project scope may hinder implementation in many cases. Source: A. Zhivov, Central Solar Hot Water Systems Design Guide (Draft), US Army Corps of Engineers (2011).

[iii] Department of Defense Strategic Sustainability Performance Plan FY 2010.

[iv] Department of Defense Strategic Sustainability Performance Plan FY 2010.